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# THE MARK III HAPLOSCOPE

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16. Abstract  A computer-operated binocular vision testing device has been developed as one part of a system designed for NASA to evaluate the visual function of astronauts during spaceflight. This particular device, called the MARK III Haploscope, employs semi-automated psychophysical test procedures to measure visual acuity, stereopsis, phoria, fixation disparity, refractive state and accommodation/convergence relationships. Test procedure are self-administered and can be used repeatedly without subject memorization. The Haploscope was designed as one module of the complete NASA Vision Testing System. However, it is capable of stand-alone operation. Moreover, the compactness and portability of the Haploscope make possible its use in a broad variety of testing environments.					
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## 1.0 INTRODUCTION

### 1.1 Purpose

The purpose of this report is to describe the design and function of an automated binocular vision testing instrument called the Baylor Mark III Haploscope. This instrument has evolved as part of a long range NASA program to develop a coordinated vision testing system (NASA Vision Testing System or NVTs) to measure the visual function of astronauts during spaceflight. The Baylor Mark III Haploscope is the subject of the present report because it is the most highly developed portion of the total NVTs, and because the instrument itself has potential application both as a vision research tool and as a means to improve the delivery of eye care here on the earth.

### 1.2 Background

There are two basic reasons for measuring man's visual performance during spaceflight. First, operationally, it is important to know how well man's visual sensory system performs during extended space missions. Because it is the primary sensory system by which man perceives and interacts with his environment, man's visual capabilities are extremely important in determining what he can and cannot do at any point in time during spaceflight. The second major reason for measuring visual performance is to assess the presence and extent of changes in the physiology of the entire organism associated with the stressors of spaceflight.

The visual system is a finely tuned energy sensor and information processor with tremendous sensitivity, mobility and resolving power. Alterations in the basic physiological milieu in which it functions can only endanger or reduce its function, producing a wide variety of visual anomalies and dysfunctions. The measurement of visual function, therefore, is a convenient and operationally important way to monitor and measure man's total adaptation to spaceflight.

NASA's interest in vision goes back to the earliest manned spaceflight. A reduced acuity and astigmatism chart was taped to the instrument panel during astronaut John Glenn's first American orbital flight. This informal means of vision testing was provided so that he could report any gross visual changes occurring during spaceflight. During the Gemini series, more formal tests of visual acuity were performed using both an on-board acuity testing device and acuity targets placed on the earth near Laredo, Texas, and Carnarvon, Australia (Duntley

et al., 1968). With the exception of this one study, almost everything known about vision in space has been based on anecdotal observations rather than systematic, quantitative testing. Although these reports have consistently suggested that the visual system works as well in space as it does on the earth, many unknowns still exist. The effect of high energy ionizing radiation upon the central nervous system (and hence the visual system), and the long term effects of cardiovascular and blood chemistry changes associated with weightlessness upon the eye and other organs of the body are still to be fully explored.

In anticipation of the time when the emphasis would shift from measuring the gross parameters of man's survival in space to the comprehensive assessment of spaceflight on man's total physiology, a program was begun in 1967 to select and develop quantitative measures of visual function for use during future extended space missions.

The initial tasks of this program were to determine which aspects of visual function were most likely to be affected by the stressors of space, and to select appropriate methods for measuring these functions during spaceflight. On the basis of an extensive analysis of available data relating visual function to such stressors as vibration, thermal stress, confinement, high luminance non-ionizing radiation, ionizing radiation, acceleration and zero-gravity, a basic set of visual function tests was selected (Decker et al., 1968), and work begun on the development of the instrumentation and procedures for testing these parameters in space. This research has resulted in the development of a coordinated vision testing system (NASA Vision Testing System or NVTs), and as part of the NVTs, the Baylor Mark III Haploscope.

### 1.3 The NASA Vision Testing System (NVTs)

The NASA Vision Testing System has been designed as a totally self-administering vision tester to be used by the astronaut to obtain a permanent, quantitative record of his visual performance. The NVTs is capable of monitoring a number of sensitive indicators of change in visual performance in the four following categories:

1. Binocular Vision
2. Visual Fields
3. Retinal Thresholds
4. Intraocular Pressure

A block diagram of the major components of the NVTs is shown in Figure 1. The hardware needed to monitor visual performance in the four test categories is contained in the three test modules. Other

components of the NVTs include an electronic computer/control system which provides programmable control of all tests and stores the data obtained, a push-button response unit that allows the subject to enter his responses to the vision tests, and a central light source which provides appropriate illumination to the three test modules. An artist's rendition of a flight-qualified version of the system is shown in Figure 2.

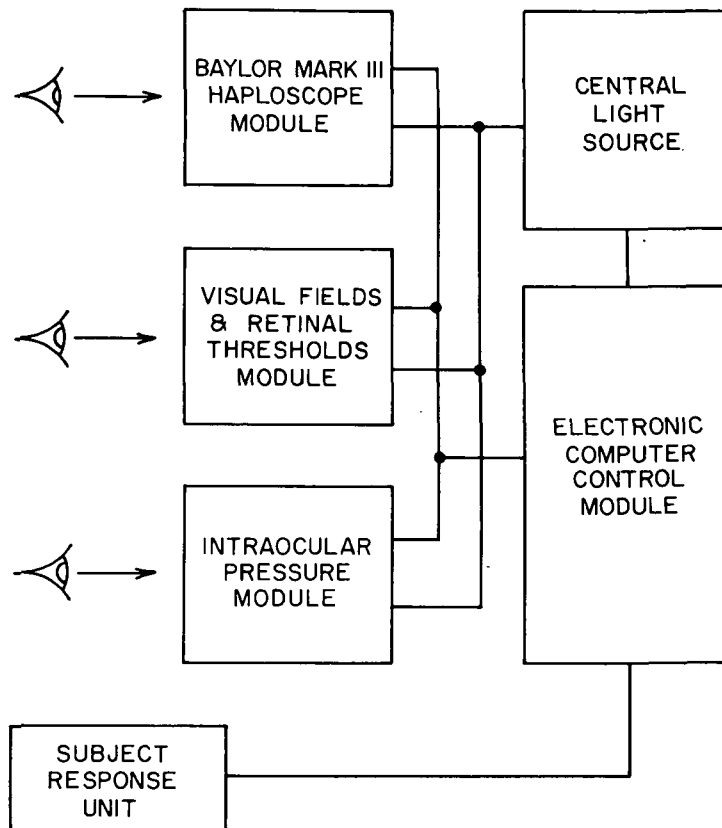


Figure 1. Block Diagram of the Major Components of the NASA Vision Testing System (NVTs).

During the course of the research program, work on the three test modules has progressed concurrently with emphasis shifted from one module to another according to the specific requirements of each module at each stage of development. For example, the intraocular pressure module has received relatively little attention since early in

the development phase. At that time, studies were carried out on a commercially available clinical device for measuring intraocular pressure (the American Optical Non-Contacting Tonometer) to determine the reliability and validity of the measurement technique (Decker et al., 1971). On the basis of these data, a decision was made to incorporate a modified version of this instrument, requiring minimal development effort, into the NVTs design.

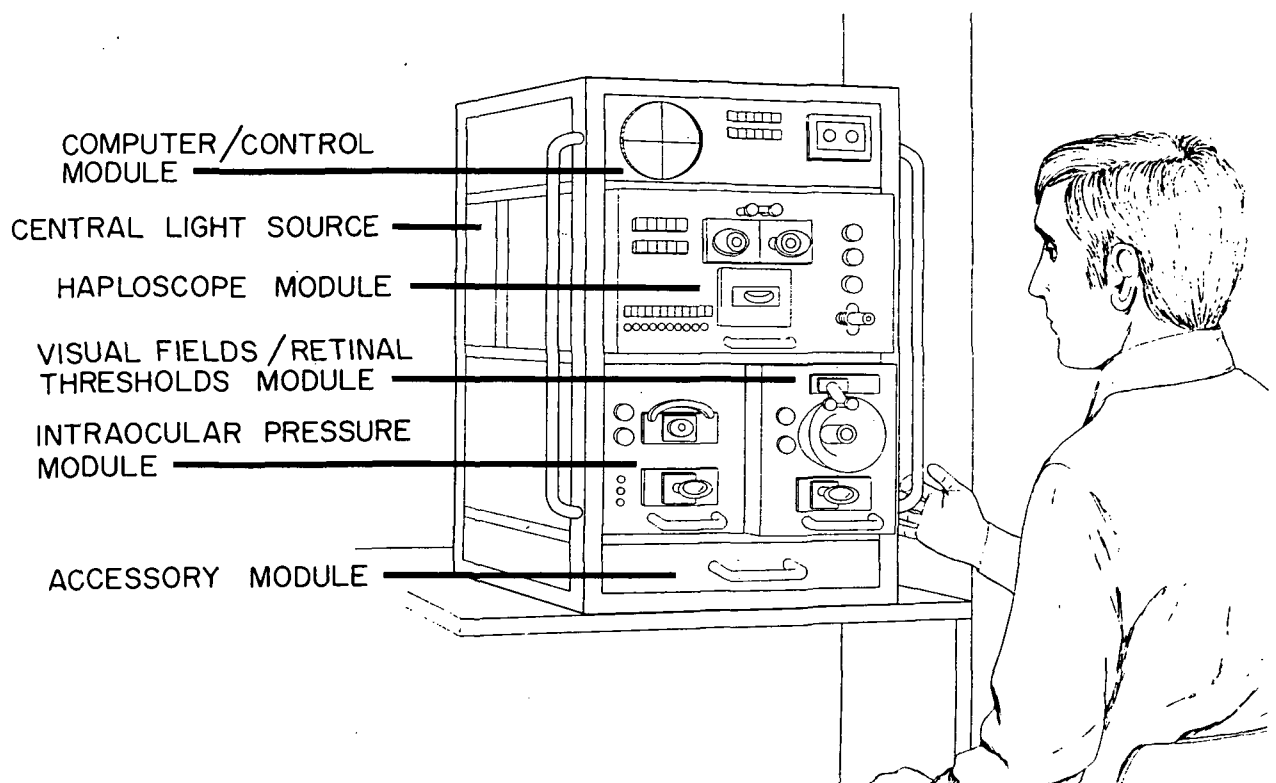


Figure 2. Artist's Rendition of the Flight Version of the NVTs.

The visual fields measurement technique adopted is patterned after Lynn's computer-controlled static perimetric technique (Lynn, 1972). A bread-board version of this module has been designed and constructed. The next stage will be an extensive laboratory evaluation to determine the specific design and test procedures needed for use as a test module in the NVTs.

The most fully developed testing approach utilized in the NVTs, however, is contained in the module devoted to the measurement of binocular vision. This aspect of the NVTs required extensive research, and development. The Baylor Mark III Haploscope has evolved as a laboratory version of the binocular testing portion of the NVTs shown in Figures 1 and 2.

## 2.0 THE BAYLOR MARK III HAPLOSCOPE

### 2.1 Purpose

The term "haploscope" comes from the Greek word "haplos" meaning single, and was defined by Hering as an "...appliance by means of which each eye is offered a separate visual field, the contents of both being united and thus brought to view in the visual field..." (Knoll, 1959). In other words, a haploscope is an instrument that presents separate images to each of the observer's eyes, so that the images are perceived by the observer as a single visual stimulus in his field of view. A haploscopic type instrument is particularly useful in testing binocular vision because it reproduces the demands of the visual world upon binocular visual function, and hence can be used to elicit visual responses that reflect the basic operating parameters of the observer's binocular system. Historically, much of what we know about binocular vision has been learned with the aid of haploscopes and clinical haploscopic devices such as the Telebinocular, the Troposcope, the Amblyoscope and the Major Synoptophore.

### 2.2 Organization of the Haploscope System

Ultimately, the Haploscope will operate as one of the modules in the NASA Vision Testing System utilizing a common computer/control system, common light source and so on (see Figure 1). For developmental purposes, however, it was necessary to make the laboratory version of this test module capable of stand-alone operation. This requirement necessitated the acquisition of such support equipment as a dedicated mini-computer, computer terminal and other peripheral devices, which would exist in some other form in the spaceborne version of the NVTs (e. g., a specialized computer and control panel would be used instead of a terminal). Because the present report is intended for potential users of the Haploscope for earth-bound problems, it will be described as it exists in its current laboratory form.

The Mark III Haploscope consists of the following major elements:

1. The Haploscope (optics and mechanics)
2. The Subject Response Unit (push-buttons for responses)
3. The Haploscope Light Source Unit
4. The Haploscope Control Unit (manual controls and electronic circuitry)

5. The Peripheral Interface Unit (interface to the computer)
6. The Haploscope Computer
7. System Peripheral Devices (teletype, disk, etc.)

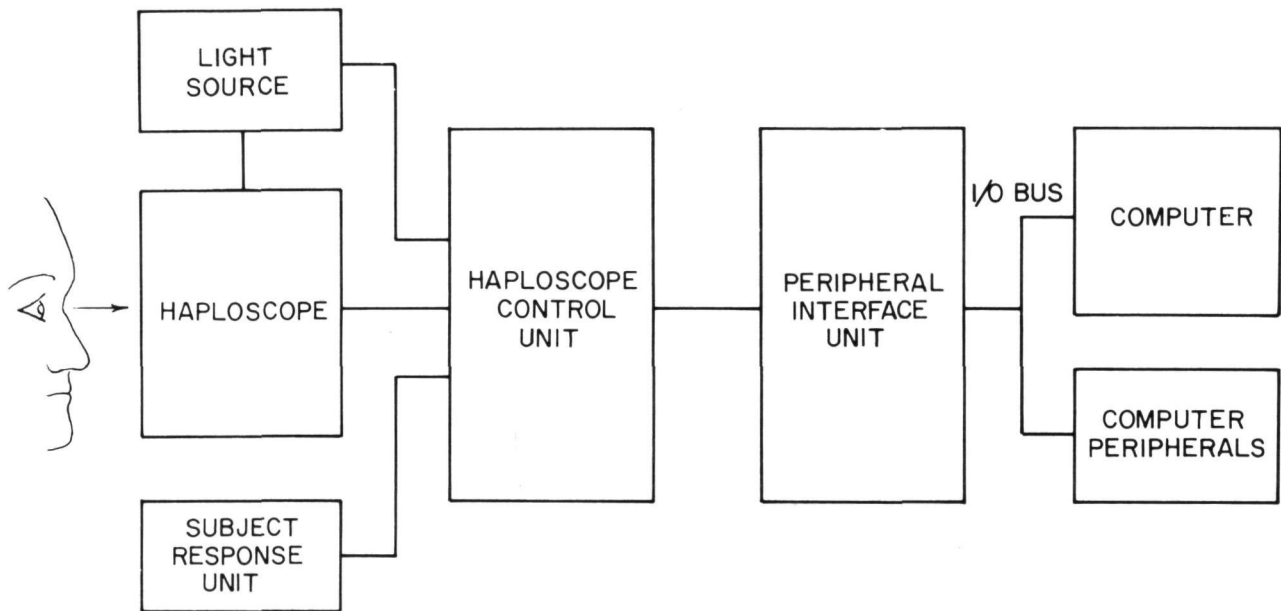


Figure 3. Block Diagram of the Baylor Mark III Haploscope System.

Figure 3 shows a block diagram of the Haploscope system. The Haploscope houses the optics and mechanics used to present visual targets to each eye. A photograph of the Haploscope is shown in Figure 4. The subject's chin rests on the lower white support, while he views the target through small windows in the left and right optical assemblies. The subject's forehead is steadied by the upper white support shown in the photograph.

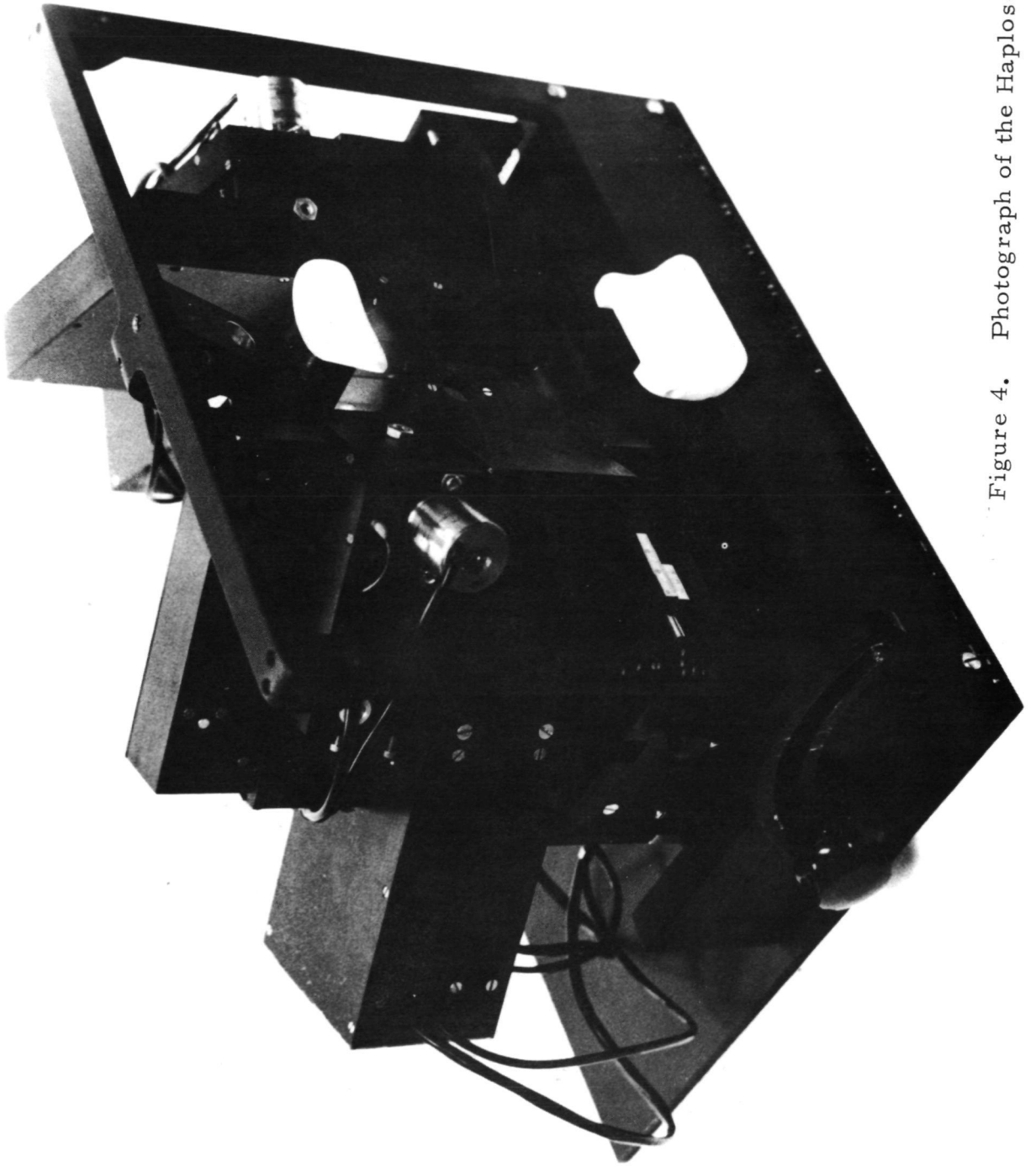


Figure 4. Photograph of the Haploscope.



The subject interacts with the testing system through the Subject Response Unit (Figure 5). This unit contains an arrangement of five small push-button switches that are used by the subject to enter his test responses. The unit can be mounted below the Haploscope or held in the subject's hand.

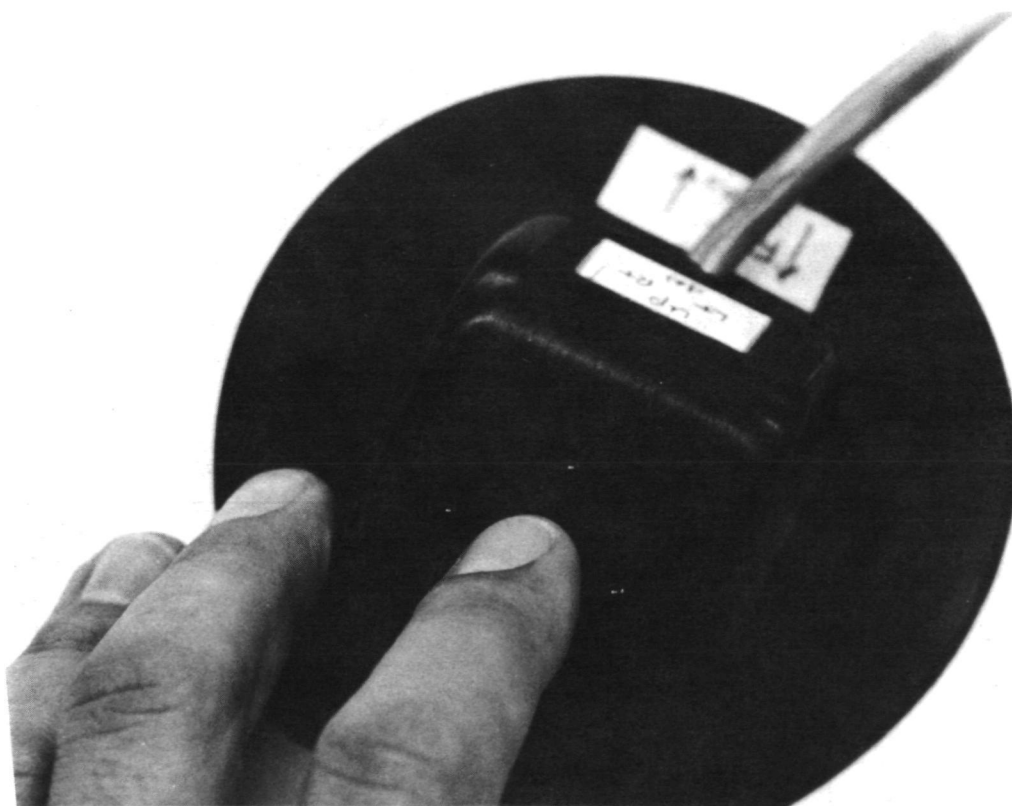


Figure 5. Photograph of the Subject Response Unit.

The Haploscope Light Source and a side view of the Haploscope are shown in Figure 6. The Light Source is a modified fiber optic illuminator equipped with four solenoid shutters to control the light traveling through the fiber optic bundles to the Haploscope. Light provided by these fiber optics illuminates the test targets viewed by the subject.

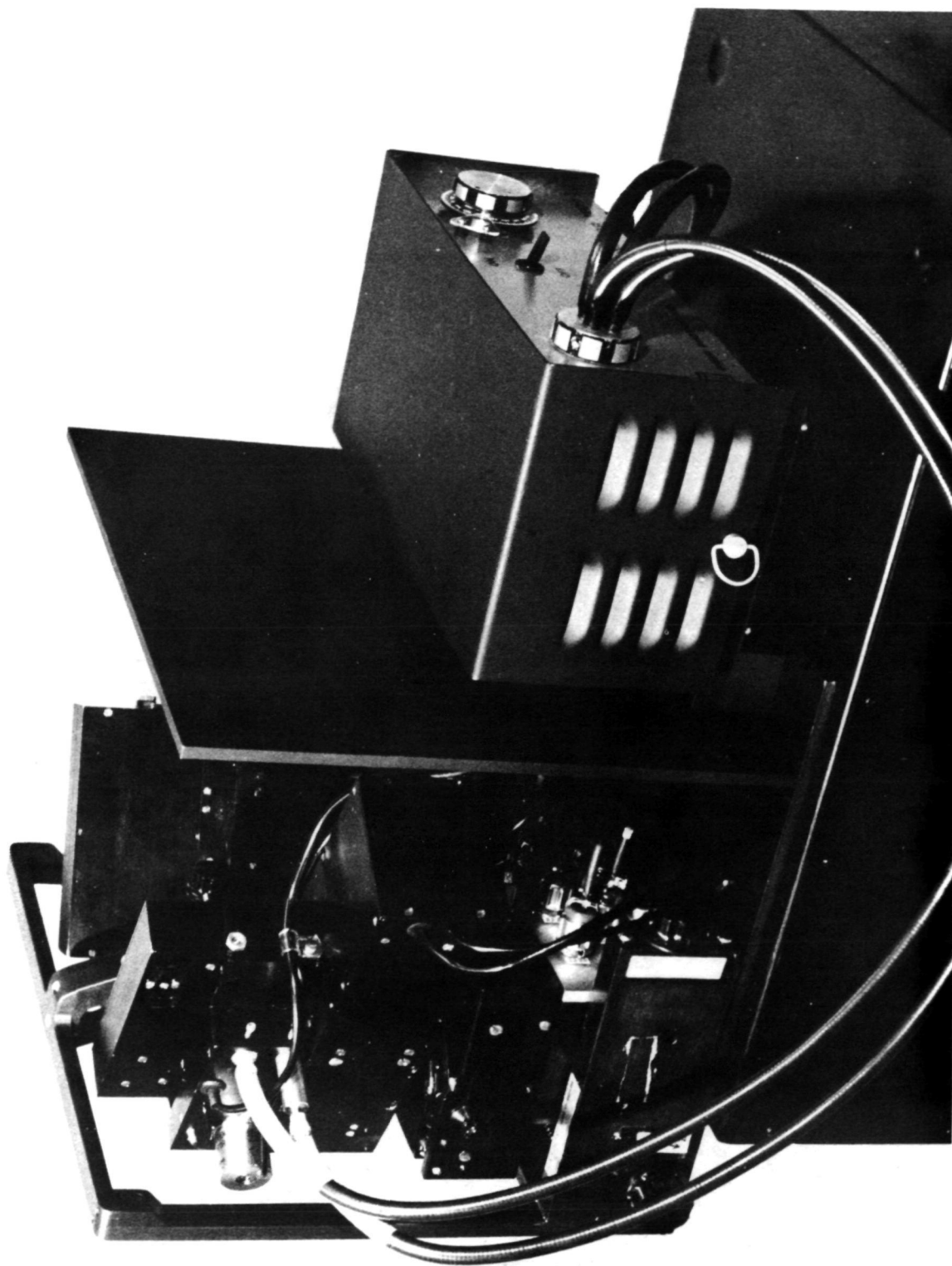


Figure 6. Photograph Showing the Light Source, the Fiber Optics and the Haploscope.

The Haploscope Control Unit houses the servo circuits, which control the operation of the motors and shutters located in the Haploscope and the Light Source. Manual switches and positional readouts for the five servo systems in the Haploscope (right film target, left film target, right stimulus to accommodation, left stimulus to accommodation and vergence angle) are located on the front panel of the Control Unit.

The Peripheral Interface Unit houses the integrated circuits and analog modules which process inputs and outputs from the Haploscope system for the I/O bus of the computer. The Haploscope Computer is a Data General NOVA 1210 with 16 K words of 16-bit core. The entire system can be operated either from the Control Unit switches in a manual mode, or by the computer under programmable control. The support System Peripheral Devices include a dual cassette magnetic tape, a teletype terminal, a high speed tape reader and punch, a disc memory system, and a medium speed line printer.

Figure 7 shows the electronics used to operate the Baylor Mark III system. The right-hand relay rack in the picture contains (from top to bottom) the system power supplies, the Haploscope Control Unit, the Peripheral Interface Unit, the Haploscope Computer, and the dual cassette magnetic tape unit. The left hand rack houses (from top to bottom) the high speed tape reader and punch, and the disc and disk controller. The system teletype terminal is shown in front. Figure 8 shows the entire Baylor Mark III Haploscope system with a subject seated in position in front of the Haploscope and an operator at the teletype.



Figure 7. Photograph of the Haploscope Electronics.

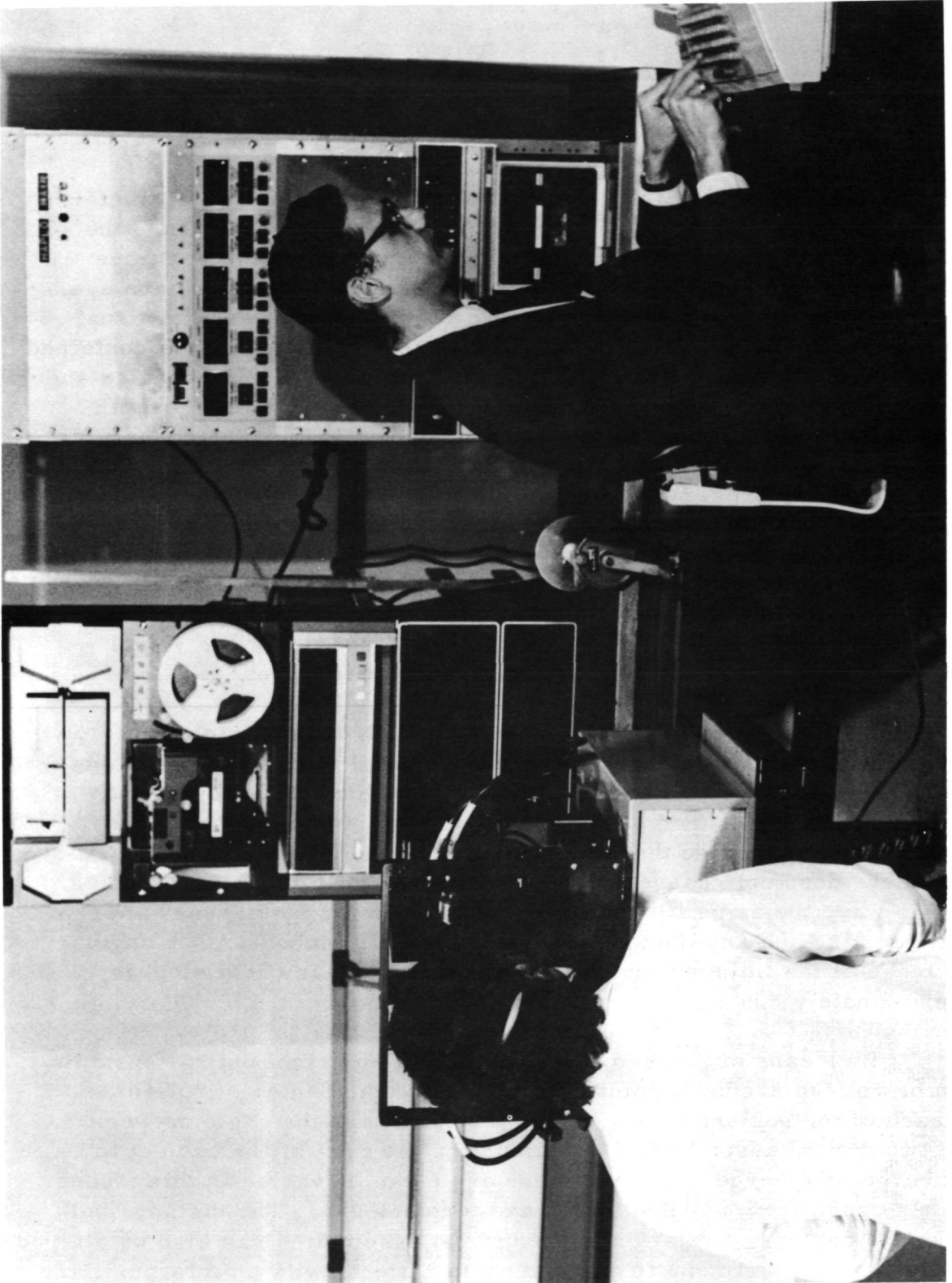


Figure 8. Photograph of the Baylor Mark III Haploscope.

## 2.3 Functions

### 2.3.1 Visual Target Presentation

The Haploscope is designed to vary three stimulus parameters: 1) the optical distance of the target from the subject, and hence the stimulus to accommodation for either or both eyes; 2) the vergence angle between the optical assemblies that present targets to each eye, and hence the stimulus to vergence eye movements; and 3) the visual targets themselves. Targets for the different vision tests are contained in the 100 individual frames of a 16 mm film loop. The mechanics and optics of the Haploscope are capable of presenting to either or both eyes any of the targets from the 100 frame film loop. The observer's level of light adaptation and the relative stimulus to accommodation to each eye are preserved when the film targets are changed by automatically substituting a blank field of equivalent luminance at an identical optical distance whenever the film loop is moved. When the film loop has traveled to the selected frame, the blank field is turned off and the new target is presented. This sequence occurs so rapidly that the subject never sees the film loop move; he sees only one visual target, a momentary blank field and a new visual target.

Each of the two optical systems through which the observer views the targets is designed to vary the optical distance or stimulus to accommodation continuously over a range from +6.3 diopters to -7.5 diopters (measured at the apex of the subject's cornea). The optics are arranged so that the angular subtense of the visual target at the eye does not change as the stimulus to accommodation changes. In this way, the same film targets can be used for both "near" and "far" testing and anywhere within the range noted above. The angular subtense of the field within which the targets appear (field stop) is approximately  $3.5^{\circ}$ .

By means of a servo system, the left and right optical systems can be rotated around a point coincident with the center of rotation of each of the subject's eyes. This motion alters the angle between the two optical assemblies and stimulates the eyes of the subject to converge or diverge. The vergence angle can be varied in this manner over a range from  $24^{\circ}$  eso to  $14^{\circ}$  exo for each eye. The distance between the centers of rotation of the optical assemblies can also be altered by a manual adjustment to accommodate patients with an interpupillary distance range from 54 to 84 mm.



### 2.3.2 Psychophysical Testing Procedures

In order to maximize the reliability of the data obtained, the test protocols developed are based upon psychophysical testing procedures that use the subject as an active participant in the test rather than as a passive observer.

Although the test procedures used are described in detail in Section 6 of this paper, the use of the subject as an active participant is illustrated in the following description of the visual acuity measurement procedure employed. The subject first views a large supra-threshold Landolt C acuity target with the gap in either the up, down, right or left positions. The subject responds by pressing one of the 4 push-buttons of the response unit that corresponds to the position of the gap. According to the test protocol, when the subject makes the correct response to the acuity target, the next target is smaller (higher acuity); when his response is incorrect, the subsequent target is larger (lower acuity). Over the course of a series of trials, the subject actively determines the stimulus presentation sequence through his own responses. In this manner, the subject "adjusts" the critical dimension of the visual stimuli until he reaches his acuity threshold.

This type of procedure is similar to that used by Crossman et al. (1970) and is related to the "staircase" psychophysical method described by Cornsweet (1962). The same basic principle is applied to the other tests performed with the Haploscope (e.g. increasing and decreasing disparity with stereopsis targets).

There are numerous advantages to the use of interactive testing procedures in the Haploscope. First, there is no way for the subject to memorize the test sequence as contrasted to the situation where, for example, an acuity test is performed repeatedly with a standard wall chart. Second, the test duration is greatly reduced. Third, the test can be administered consistently and accurately without requiring the participation of a trained examiner. Fourth, active subject participation, particularly where repeated determinations of thresholds over extended periods of time are required, improves subject attention and motivation. For the purposes of testing vision during long spaceflight missions, such considerations are of considerable importance.

The ability to perform such interactive testing is provided in the Haploscope by the system computer. With its capability of carrying out a large number of tasks in a very short time, testing paradigms which would be impossible or impractical in human

administered tests are easily accomplished in a programmable testing system. As noted in later sections, the application of such testing techniques may be one way to improve the quality and efficiency of eye care delivery here on the earth.

### 2.3.3 Test Capabilities

The flexibility of the Haploscope system in terms of the availability of a variety of test targets and programmed test procedures enables the Haploscope to evaluate numerous aspects of both monocular and binocular visual performance, including the following:

- Lateral Phoria
- Vertical Phoria
- Cyclophoria
- Fixation Disparity
- Refractive State (sphere, cylinder and axis)
- Acuity (binocular and monocular)
- Stereoacuity
- Accommodative ranges
- Accommodative/Convergence relationships



### 3.0 HAPLOSCOPE OPTICS

#### 3.1 The Right and Left Optical Assemblies

The basic design of the optical system used to present a target to each eye is shown in Figure 9. An erector lens ( $L_1$ ) is placed at twice its focal length ( $u_{L_1}$ ) from the film plane. A real image of the film plane is formed at twice the back focal length ( $v_{L_1}$ ) of lens  $L_1$ . This image becomes an object for the Badal lens ( $L_2$ ) which is placed at its back focal length ( $v_{L_2}$ ) from the entrance pupil of the subject's eye. By means of a movable Porro prism (not shown), the distance ( $u_{L_2}$ ) between the film plane image and the Badal lens is varied. As this distance changes, the vergence of the light at the subject's eye is altered linearly. It can be shown (Ogle, 1961) that the vergence  $V$  of the light at the exit pupil of the system varies as:  $V = F_b^2 x - F_b$  where  $F_b$  equals the dioptric power of the Badal lens, and  $x$  is the distance between the Badal lens and the object (in this case the film plane image).

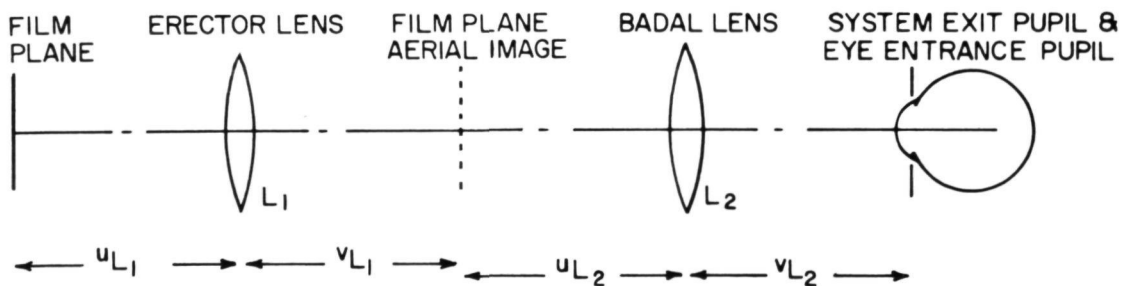


Figure 9. Diagram of the Basic Optical System.

In addition to the convenience of a linear relationship between distance  $x$  and vergence  $V$ , an added advantage of this system is that the angular size of the film plane image remains constant as the vergence changes. Thus the angular subtense of the target viewed by the subject through the optics does not vary as the vergence of the light rays at the entrance pupil changes. This feature permits the use of the same visual targets in the film plane for both near and far testing.

Although the Haploscope optics utilize the basic erector and Badal lens arrangement described in Figure 9, the physical space limitations of the Haploscope require that the optical path be folded to a more compact form. Figure 10 shows the actual prisms and other non-refracting optical components used to house the 55 cm path length in an area roughly 6 x 20 x 7 cm. These components are arranged diagrammatically in the figure to illustrate their function rather than their actual spatial arrangement in the optical assemblies.

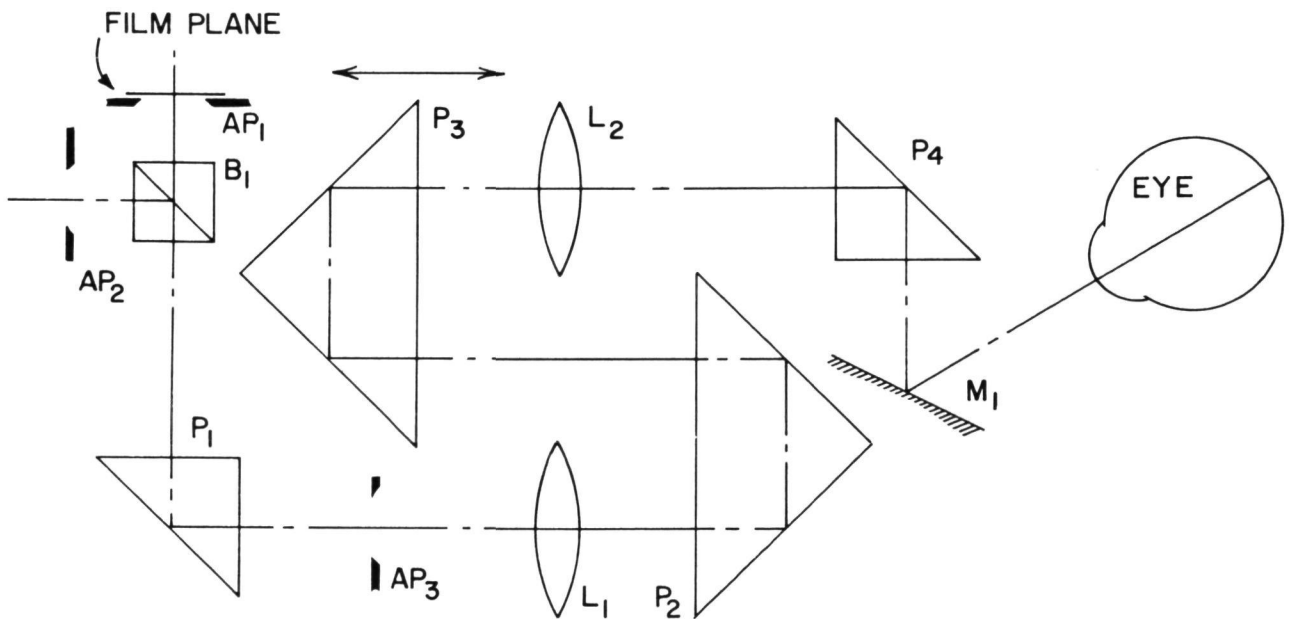


Figure 10. Diagram of the Refracting and Non-refracting Optics of the Haploscope.

Beamsplitter  $B_1$  is used to substitute a blank field ( $AP_2$ ) for the film target field ( $AP_1$ ) whenever the film loop targets are changed or whenever appropriate in the testing procedures. Prism  $P_1$  diverts

the optical path  $90^\circ$ . Aperture  $AP_3$  is positioned so that it is imaged in the exit pupil of the optical system, forming the aperture stop of the system limiting the exit pupil to a 5 mm diameter. Lens  $L_1$  is the system erector lens (A Jaeger, 64 mm F.L.). Porro prism  $P_2$  folds the optical path  $180^\circ$  and directs the rays into the Badal lens  $L_2$  (Rolyn Optics, 100 mm F.L.). The position of  $P_3$  is controlled by a servo system. The optical distance between lenses  $L_1$  and  $L_2$  is determined by the position of that prism. A movement of 1 cm of prism  $P_3$  changes the optical distance by 2 cm. Because the Badal lens has a back focal length of 10 cm (+10 Diopters), each centimeter of movement of  $P_3$  changes the vergence of the light at the entrance pupil of the subject's eye by 2.0 diopters. Mirror  $M_1$  and prism  $P_4$  also fold the optical path of the light rays passing through the Badal lens. Figure 11 shows the optical components of the right eye optical assembly as they are actually configured in the Haploscope.

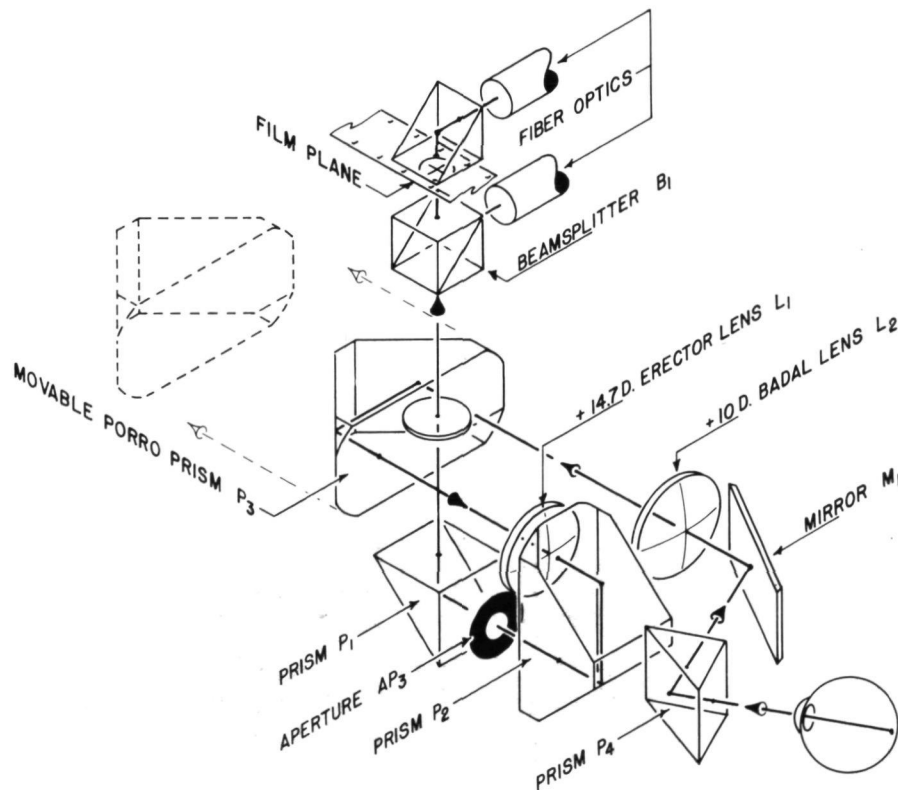


Figure 11. The Optical Components of the Right Optical Assembly as Arranged in the Haploscope.

### 3.2 The Visual Target Film System

Visual targets are provided in each optical assembly by means of a rear illuminated 16 mm film strip located in the film plane as shown in Figure 11. The equipment and procedures used to prepare these high resolution, high contrast film loops are described in Appendix A. The film strip is arranged in a continuous loop and driven so that any individual frame can be positioned for viewing at any one time. By means of a beamsplitter,  $B_1$ , a second aperture and blank field can be viewed in place of the film target. Figures 10 and 11 show how this is accomplished. Beamsplitter,  $B_1$ , is placed so that apertures  $AP_1$ , and  $AP_2$  are coincident and at the same optical distance. The target film is placed behind  $AP_1$ , and is illuminated by means of a fiber optic, a right angle prism and a diffusing plate. Aperture  $AP_2$  is illuminated by a separate fiber optic, and diffusing plate. By activating shutters placed in front of each fiber optic at the light source, either the target plane or an equal luminance blank field can be illuminated at any time. This is accomplished automatically by the system electronics whenever the test film is moved from frame to frame. In this way, the observer never sees the target imagery moving across aperture  $AP_1$ , and the level of illumination and stimulus to accommodation remain at a constant level. When both fiber optics are illuminated, the contrast of the imagery is reduced by 50%, and the total luminance of the field is doubled.

### 3.3 The Light Source

The light source is a quartz-iodine 150 watt lamp contained in a modified lamp housing. Figure 6 shows a photograph of the light source and the four fiber optics used (two for each optical assembly). The fiber optic holder of the housing has been altered to include a solenoid driven shutter for each of the fiber optics. An adjustable aperture is mounted in front of each of the four fiber optics to vary the amount of light going into each fiber optic and to balance the luminance of the fields.

#### 4.0 MECHANICAL ASSEMBLIES

The Baylor Mark III Haploscope instrument consists of the sub-assemblies shown in Figure 12. The Sub-Base supports the Haploscope and houses the system stepper motor driving circuits. The Mechanical Base is comprised of the mechanisms for rotating each optical system around the center of rotation of its respective eye, and changing the distance between these centers according to the interpupillary distance of each subject. The right and left Optical Assemblies house the major part of the optical systems of the Haploscope. The two Cassette Holders rest on top of each of the Optical Assemblies and support the film loop visual target Cassettes. The Support Frame sits in front of the Haploscope as shown in the diagram of Figure 12, and the photograph in Figure 4. This frame provides the chin and forehead rests which hold the subject's head in position. A flat plate and hinge mounted to the bottom of the support frame can be used to tilt the entire Haploscope  $90^{\circ}$  from its usual operating position. In this way, the system can be used to measure the visual function of supine subjects (i.e., in bed-rest studies).

##### 4.1 The Mechanical Base

The design goal of the Mechanical Base was to provide a means for rotating the Optical Assemblies through a  $40^{\circ}$  arc about two points in space which coincided with the centers of rotation of the subject's eyes in a manner which provided a rapid, accurate motion with little or no backlash. Moreover, it was required that the distance between the centers of rotation be symmetrically adjustable over a range from 54 to 84 mm.

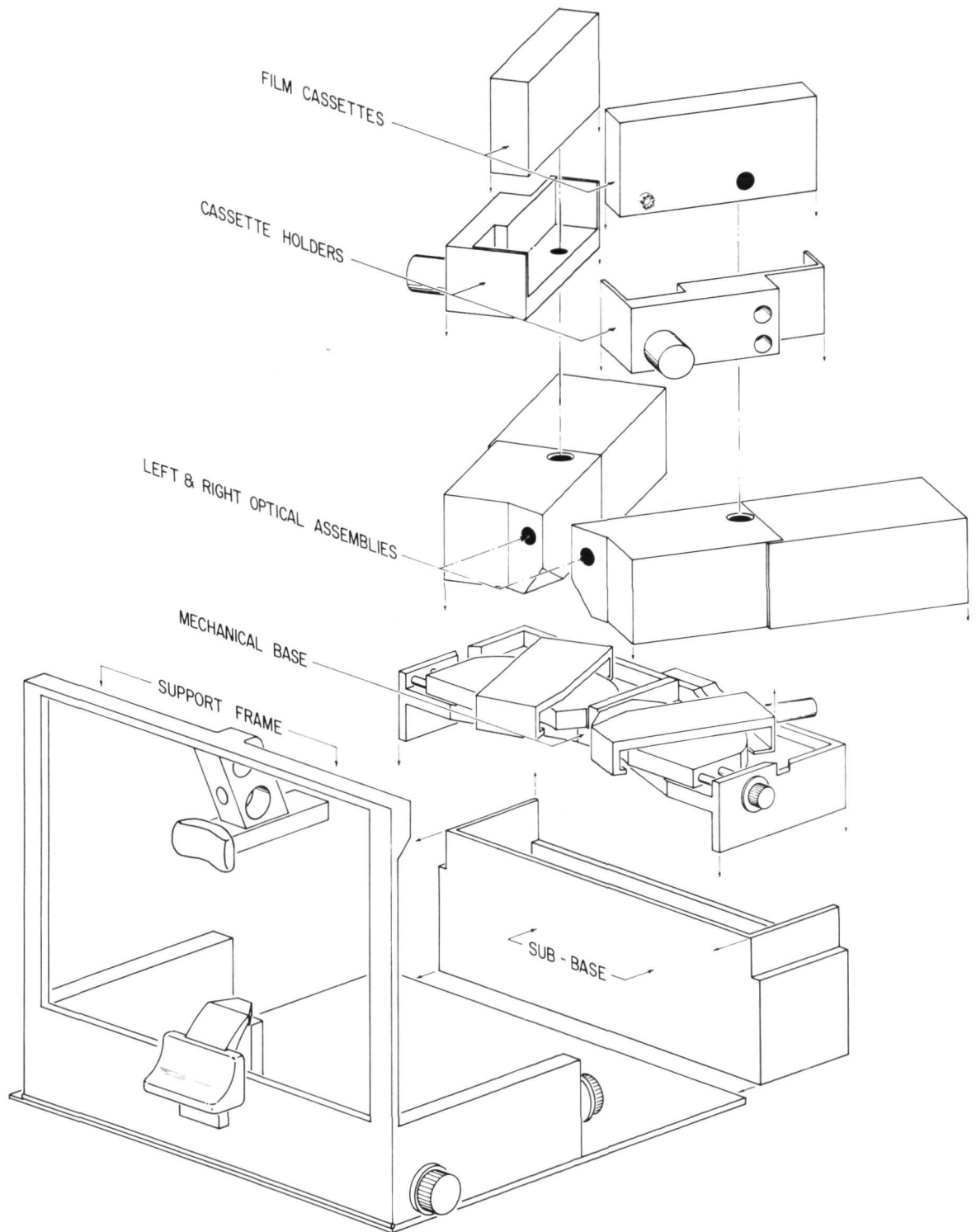


Figure 12. Diagram of the Haploscope Showing the Sub-Assemblies of the Instrument.

Figure 13 shows how this was accomplished. The Base Plate of the Mechanical Base assembly has a horizontal shaft (P.D. Adjustment Shaft) across its width (see Figure 13A). Short sections of right and left hand threaded shafting are attached to the P.D. Adjustment Shaft in cutouts at each end of the base plate. Small blocks (P.D. Block) receive the threaded shafting. A rotation of the P.D. Adjustment Shaft thus would move these blocks inward or outward symmetrically.

In Figure 13B, two flat Curved Tracks are shown supported by pairs of Horizontal Supporting Bars running in cutouts in the bottom of the Curved Tracks and attached to the Base Plate. The small blocks mounted on the right and left hand threaded portions of the P.D. Adjustment Shaft are attached to the bottom of each Curved Track. As the P.D. Adjustment Shaft is rotated, therefore, the right and left Curved Tracks are moved inward or outward symmetrically.

Figure 13C shows the "V" grooves cut in the inner and outer radii of the Curved Tracks. A small trolley (Optical Assembly Platform) is mounted on each Curved Track (shown on left Curved Track only) by means of three wheels which ride in the "V" grooves. One wheel rides in the front "V" groove, while two wheels ride in the rear "V" groove. The right and left Optical Assembly Platforms are driven by a motor attached to the Vergence Drive Shaft, which enters the center block between the Curved Tracks. The Vergence Worm and Gear attached to this shaft rotate a Threaded Shaft running laterally within each Curved Track. These Threaded Shafts are right and left hand threaded for the right and left Curved Tracks respectively. As the Threaded Shafts are rotated by the Vergence Drive Shaft, two Vergence Drive Blocks are moved inward and outward within each Curved Track. These drive blocks are supported by parallel Stabilizing Rods. A Hex Shaft and Sliding Coupling between each Threaded Shaft and the Vergence Drive Worm permits control of the position of each Drive Block, regardless of changes in the distance between the curved tracks accomplished by the P.D. Adjustment Shaft mechanism.

A Vertical Drive Pin is located in the top of each Drive Block. These pins extend up into the Optical Assembly Platform riding on the "V" grooves of each Curved Track. As the Drive Blocks and Drive Pins move inward or outward, the platforms are pushed on the curved track in a curvilinear fashion. This linear to curvilinear motion change is accomplished with minimum friction and backlash, by a "Rolamite" mechanism.

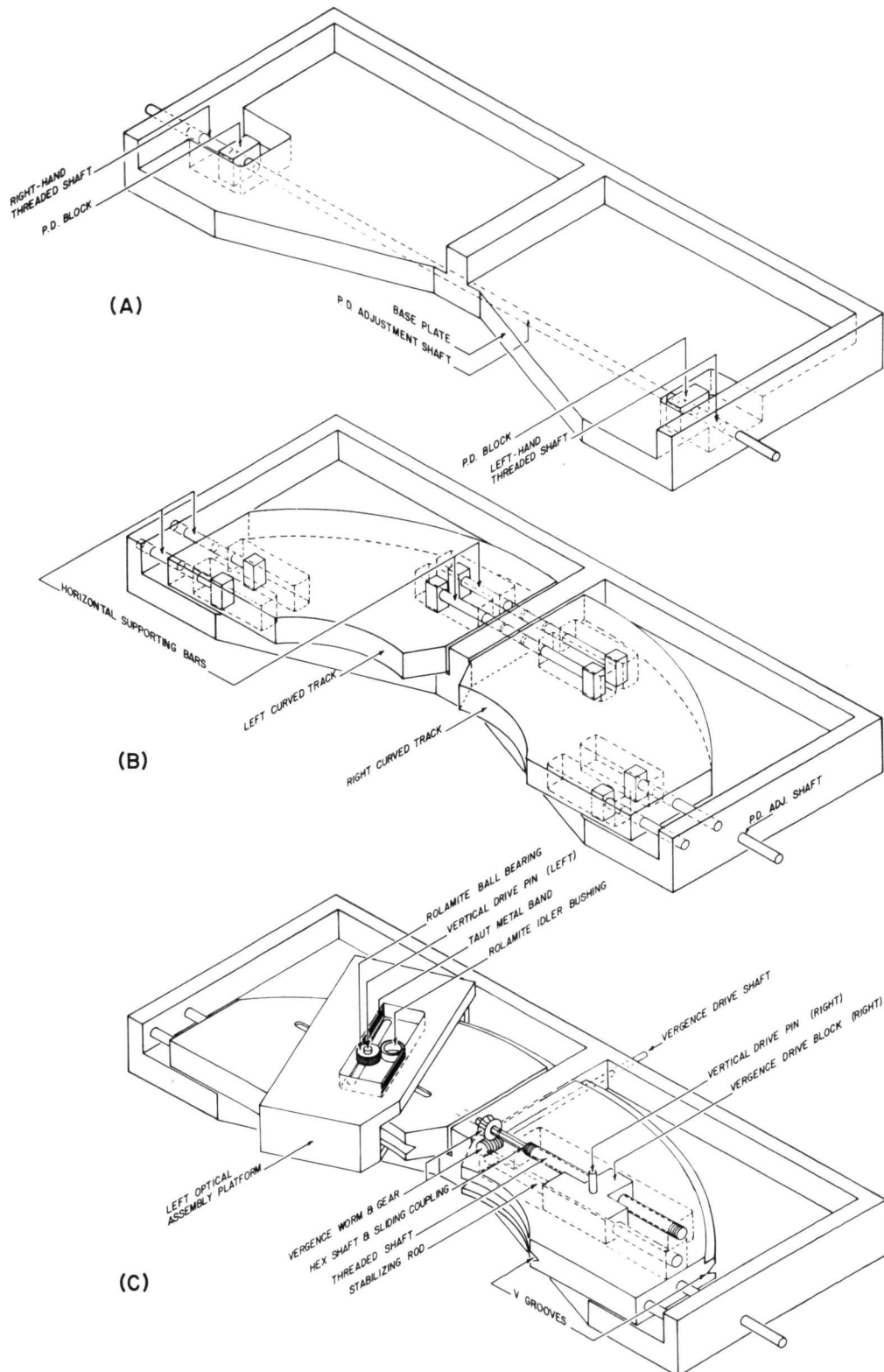


Figure 13. Three Drawings Showing the Construction of the Mechanical Base Sub-Assembly.



A small ball bearing is located on each Drive Pin that extends into the moving platform. A bushing of identical size is placed next to the bearing in a shallow cutout. A taut band of flexible metal is looped around each bearing as shown in Figure 14, and is fastened at either end of the cutout. As the Drive Pin moves laterally, the Rolamite Bearing and Idler Bushing are moved forward or backward as the platform moves around the Curved Track. As this movement occurs, the taut metal band keeps the two bearings tight against the cutout walls. Because the bearings are free to rotate, a virtually backlash free movement is accomplished without substantial friction. In this manner, rotation of the Vergence Drive Shaft moves the right and left Optical Assembly Platforms in an inward and outward direction symmetrically. The total extent of this movement is an arc of approximately  $40^{\circ}$  for each platform. Figure 14 shows a photograph of the Rolamite mechanism of the left Optical Assembly platform.

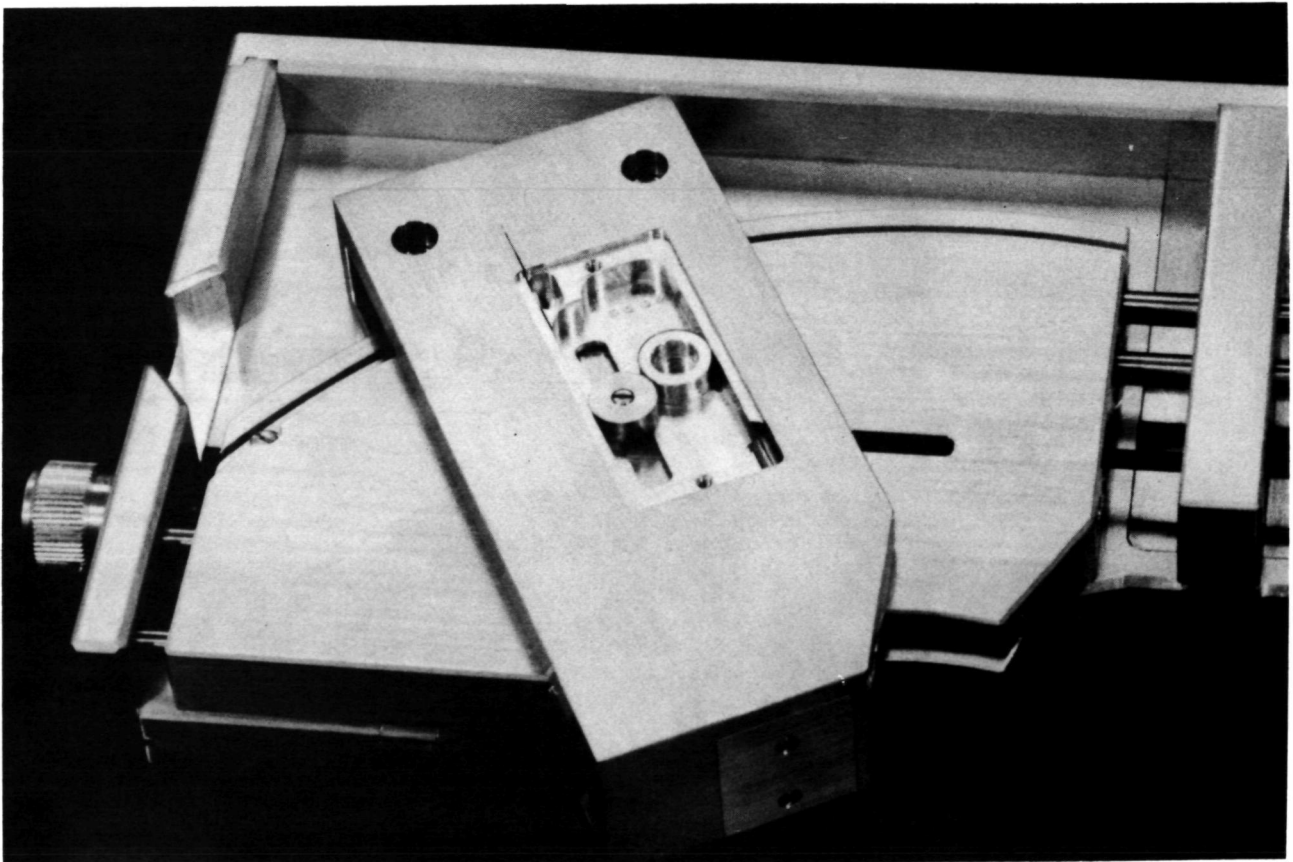


Figure 14. Photograph of the Rolamite Mechanism Located in the Left Optical Assembly Platform.

The prime mover for the vergence movement is a size 15 stepper motor mounted on the back of the base plate. A 10 tooth spur gear on the motor shaft drives a 20 tooth spur gear mounted on the Vergence Drive Shaft. Two microswitches mounted on the bottom side of the right Curved Track are activated by the movement of the Drive Block and act as limit switches for the vergence movement. Figure 15 shows the underside of the two Curved Tracks with the vergence limit switches and the vergence drive worm. The vergence angle or platform position is sensed by means of a ten turn potentiometer mounted on the rear of the right platform. A pinion gear is fixed to the shaft of a potentiometer, which meshes with a narrow rack mounted on the outer circumference of the curved track. As the platform moves on the curved track, the pinion gear is rotated by the stationary rack.

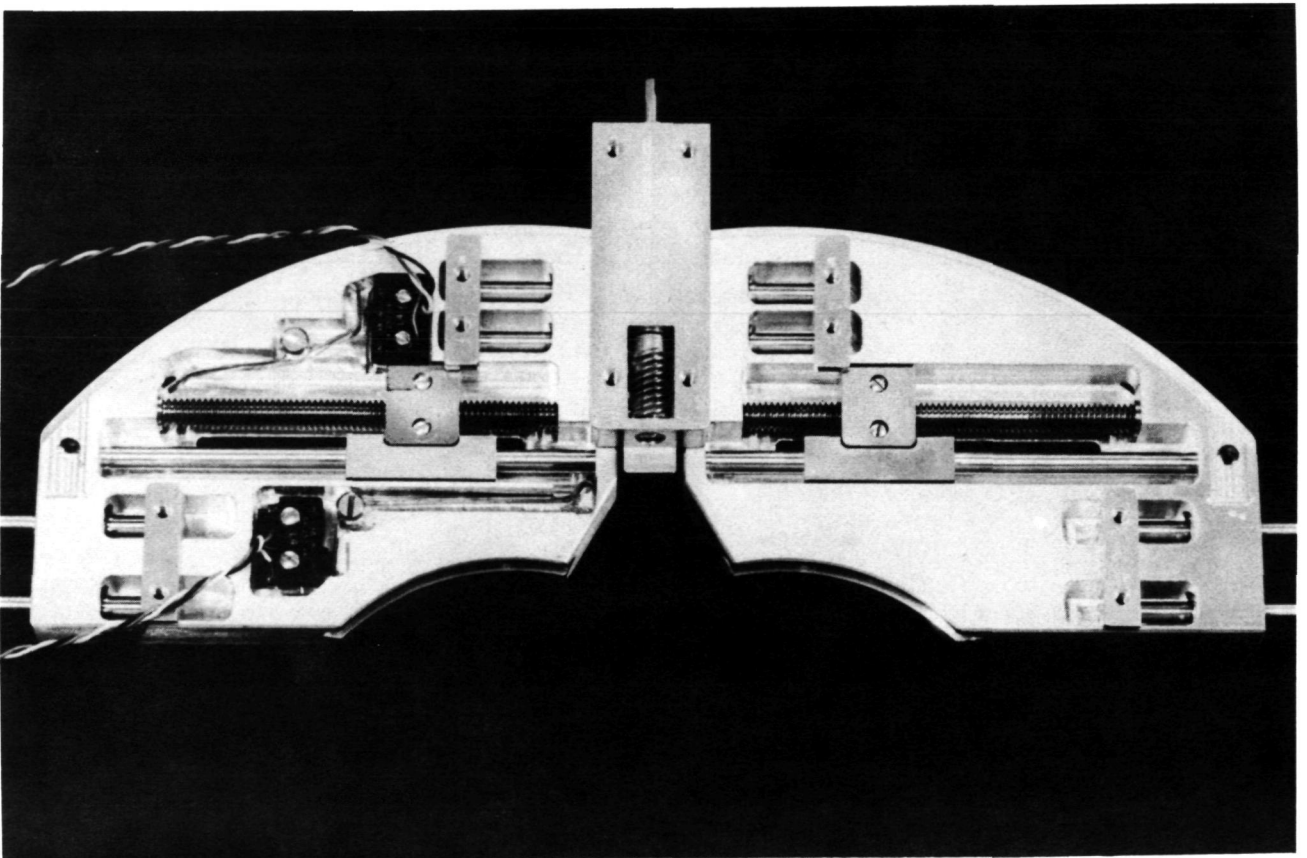


Figure 15. Photograph of the Bottom Side of the Right and Left Curved Tracks.

Figure 16 shows the entire Base Assembly with the vergence drive stepper motor detached, the potentiometer mounted in the right Optics Assembly Platform, and the stationary rack located on the right curved track. In Appendix B, Figures B1, B2, B3, and B4 are exploded parts diagrams of the Curved Track, Mechanical Base, Vergence Drive Worm and Gear Housing and Optical Assembly Platform respectively.

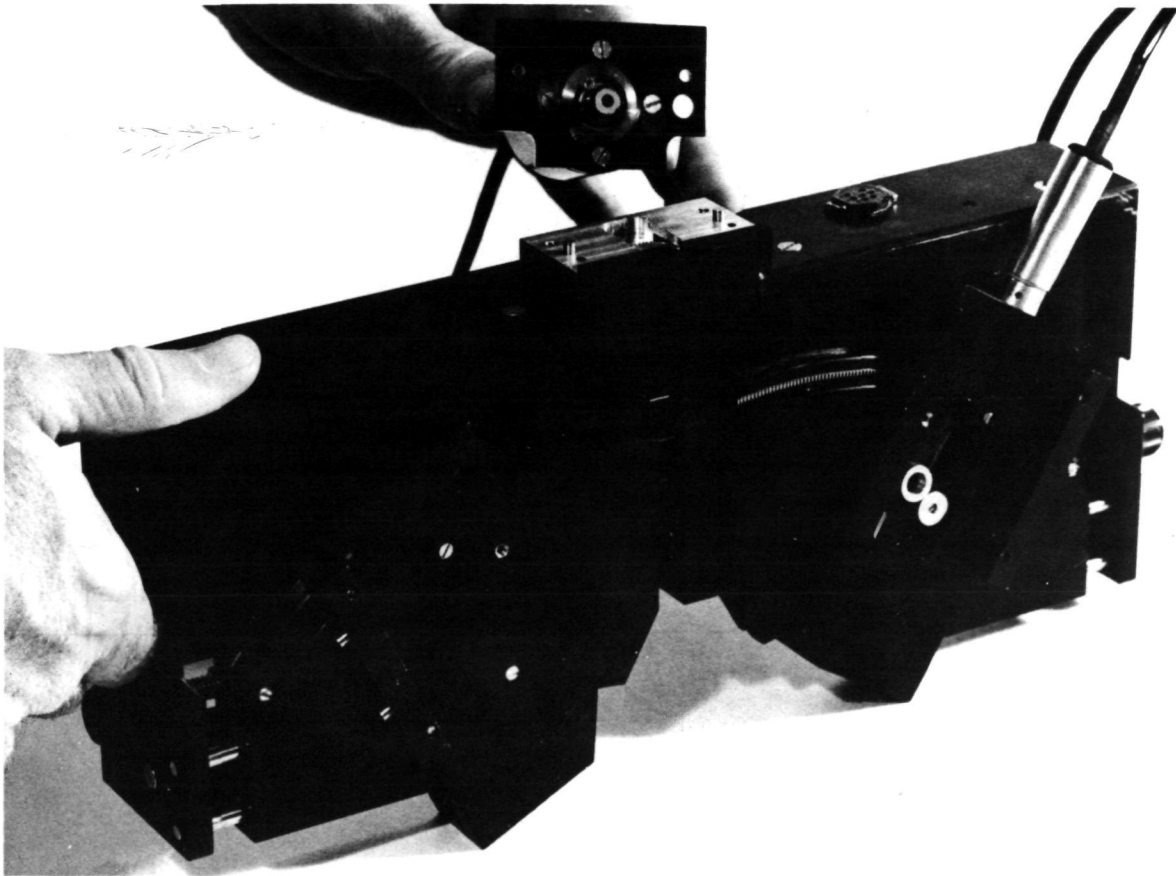


Figure 16. Photograph of the Mechanical Base Sub-Assembly.

#### 4.2 The Optical Assemblies

The right and left Optical Assemblies house the optics shown in Figures 10 and 11, and provide the mechanism for moving Porro prism  $P_3$ , thus altering the optical distance between the film targets and the eye. Figure 17 shows a view of the two parts of the right Optical Assembly. The rear portion (on the left side of the photograph)

houses prism  $P_3$ , while the remainder of the optics are contained in the front portion (on the right side of the photograph).

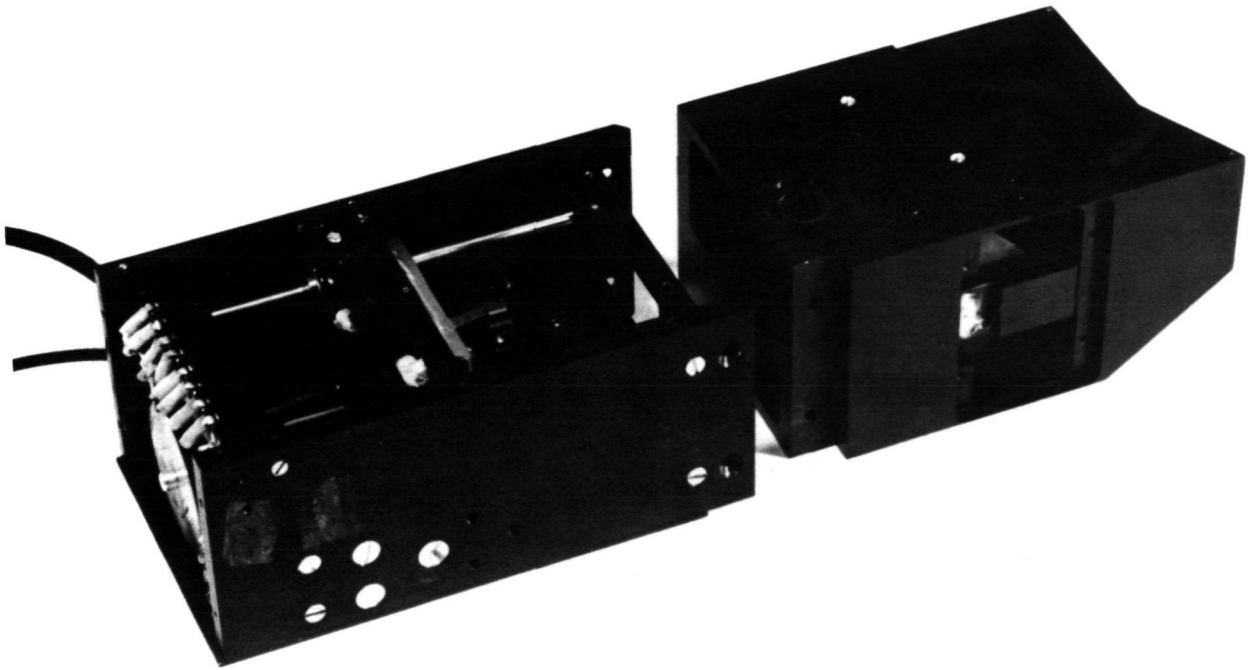


Figure 17. Photograph of the Two Parts of the Right Optical Assembly.

Porro prism  $P_3$  is mounted on a platform which is supported by three parallel steel<sup>3</sup> rods. A helix threaded shaft runs through a teflon nut just below the prism. As the shaft (accommodation drive shaft) is rotated, the prism platform and the prism are moved forward and backward along the three parallel rods. A size 11 stepper motor located in the rear portion of the optical assembly is geared to the accommodation drive shaft. A 10 turn potentiometer is also geared to the same shaft to provide a readout of the Porro prism position. Microswitches located within the housing limit the movement of the prism. Figure 18 is a photograph of the right Optical

Assembly, the Cassette Holder and the Film Cassette with the cover plates removed. Figures B5 and B6 of Appendix B show exploded parts diagrams of both the front and rear portions of the right Optical Assembly. The left Optical Assembly is constructed as a mirror image of the right Assembly.

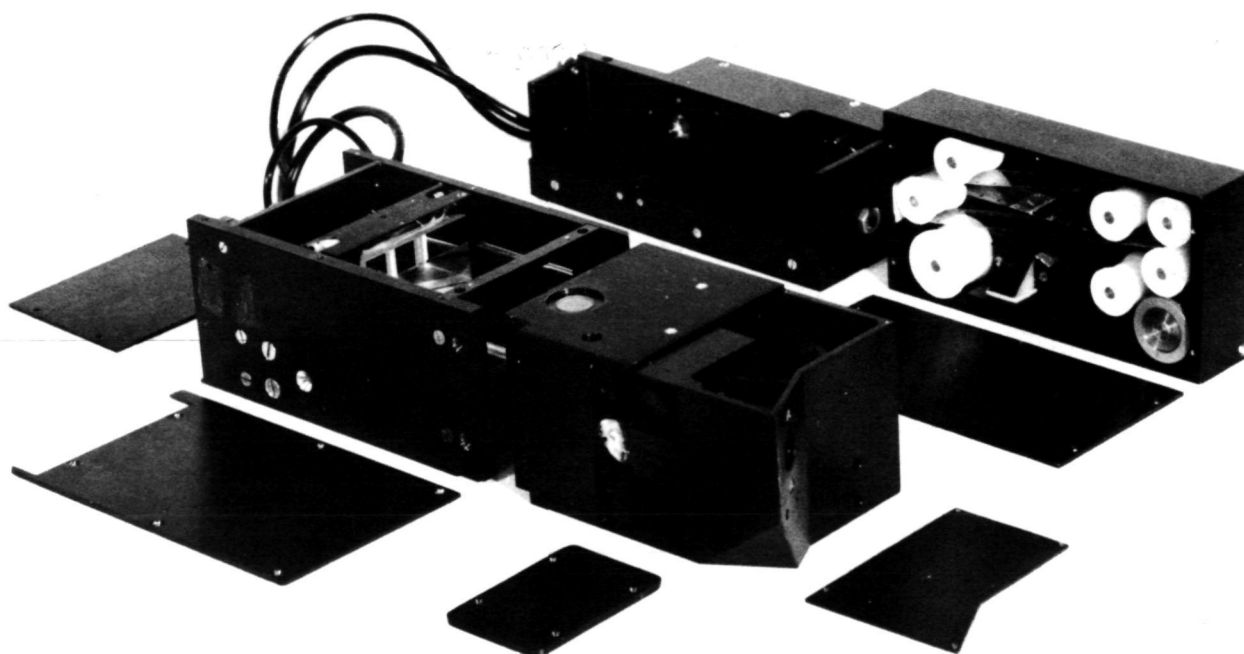


Figure 18. Photograph of the Right Optical Assembly, Cassette Holder and Film Cassette with Cover Plates Removed.

#### 4.3 The Cassette Holder

In addition to supporting the film cassette in the proper position relative to the rest of the Haploscope optics, the Cassette Holder performs a number of other functions. First, the Cassette Holder houses the stepper motor and associated mechanical parts, which move the film loop from frame to frame. Second, the Cassette Holder receives the two fiber optics which illuminate the film targets

and the blank field. Third, beamsplitter  $B_1$ , and aperture  $AP_2$  (see Figures 10 and 11), used to substitute a blank field for the target field whenever the film targets are changed, are located in the Cassette Holder.

Figure 19 is a photograph of the right Cassette Holder with its cover plate removed. The Film Cassette fits into the flat portion with the cassette aperture ( $AP_1$ ) located over the hole just to the left of the center of the photograph. On the right hand part of the photograph a 100 tooth spur gear can be seen which is driven by a size 11 stepper motor. Each pulse of the motor rotates the stepper motor's 10 tooth pinion shaft by  $45^\circ$ . Eight pulses of the motor rotate the 100 tooth spur gear by  $36^\circ$  or  $1/10$  revolution. A 16 mm film sprocket in the Film Cassette couples to the 100 tooth gear in the Cassette Holder when the cassette is in position. The driving film sprocket in the cassette has ten film perforation teeth arranged on its circumference. Hence for each  $1/10$  turn of the 100 tooth gear, the film sprocket advances the film in the cassette precisely one frame. An LED and a sensor (On Frame Sensor) are arranged on either side of the 100 tooth gear, so that each time the 100 tooth spur gear rotates by  $1/10$  turn, the LED light and sensor are aligned with one of a series of holes spaced every  $36^\circ$  on the gear. The function of this arrangement is to correctly index each frame of the cassette, and thus to indicate when the motor has moved the film one frame. Hence, for each 8 pulses of the stepper motor, the film in the cassette moves one frame and the On Frame LED/sensor verifies the movement and increments the film frame register in the control circuitry.

A small microswitch (Cassette Mounted Interlock Switch) is also mounted in the cassette adapter to indicate to the system electronics when a cassette is properly mounted. An additional LED and sensor (Zero Frame Detector) are contained in the cassette adapter to sense the zero position of the film loop. An exploded parts diagram of the Cassette Holder is shown in Figure B7 of Appendix B.

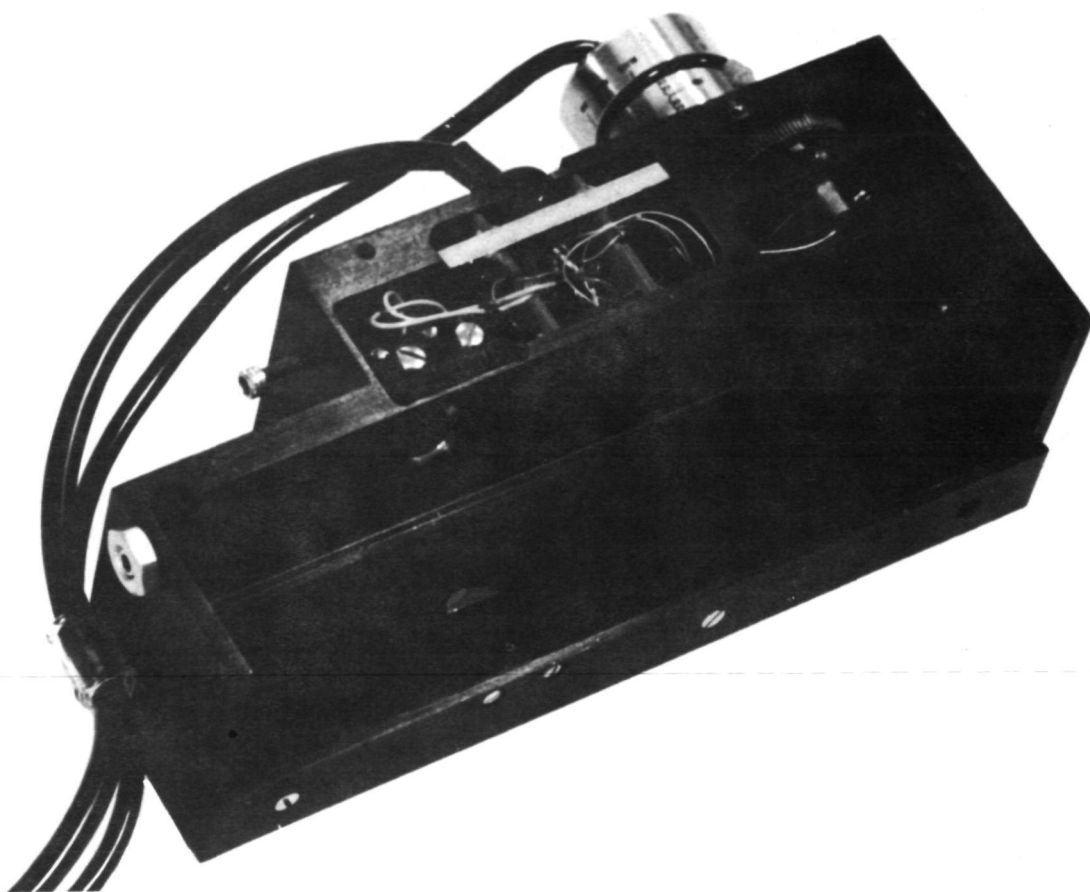


Figure 19. Photograph of the Right Cassette Holder with Cover Plate Removed.

#### 4.4 The Film Cassette

Figure 20 is a photograph of the right Film Cassette with the cover plate removed. Figure 21 is a diagram indicating the major parts of the cassette and the path of the film loop. As the film sprocket wheel is driven by the stepper motor and gears of the Cassette Holder, the 16 mm film is both pushed and pulled over the film aperture  $AP_1$ . A spring mounted pressure plate keeps the film flat over the aperture. The right angle prism contained in the cassette reflects the light from the fiber optic located in the Cassette Holder through the film plane and down into the Cassette Holder and Optical Assembly below. The diffusing screen provides an even illumination of the film plane. Two adjustable delrin rollers provide a means for adjusting film loop tension within the cassette.



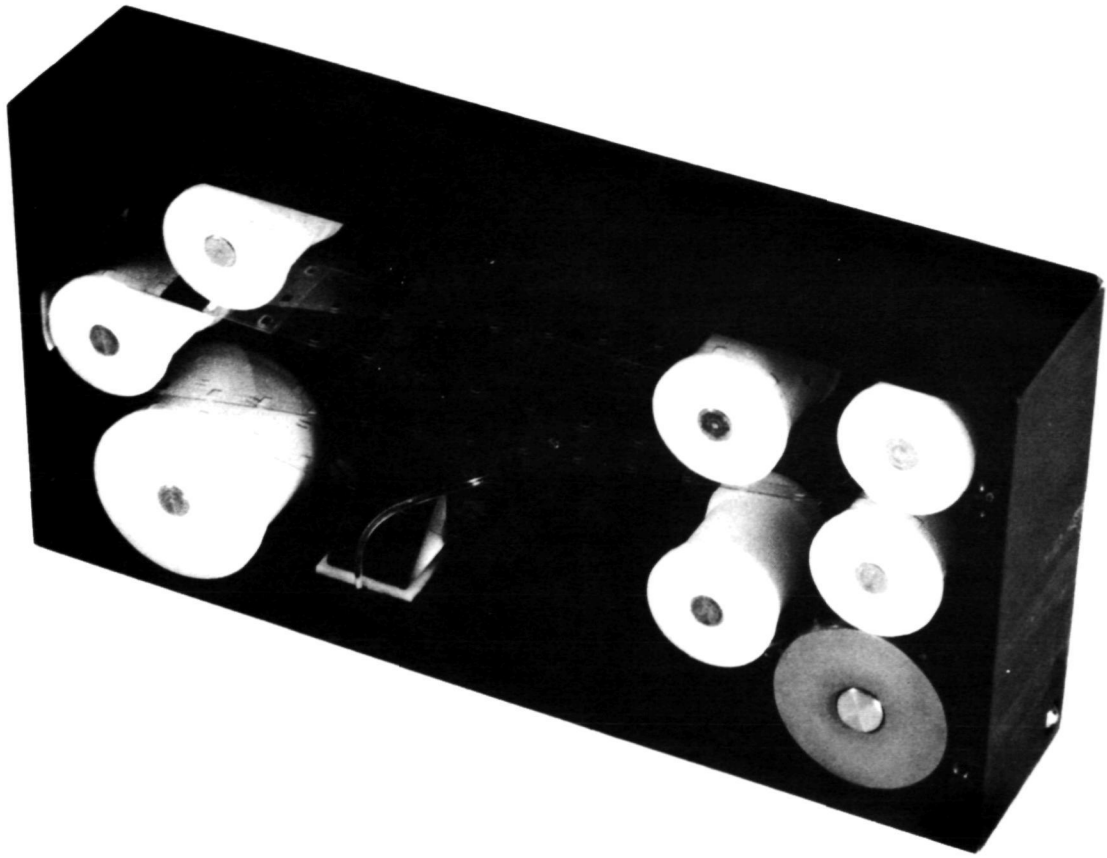


Figure 20. Photograph of the Right Film Cassette with the Cover Plate Removed.

The small curved fiber optic shown in Figures 20 and 21 near the right angle prism is part of the Zero Frame Detector used to index the zero frame of the film loop. The fiber optic extends from a hole in the pressure plate to the back of the cassette where it aligns with an IR sensor located in the Cassette Holder. An IR LED source is located in the base of the Cassette Holder just to the side of beam-splitter  $B_1$ , (see Figure 11). The IR light passes through a hole in the top of the Cassette Holder, through a second hole in the bottom of the Film Cassette, through the edge of the 16 mm film, into the curved fiber optic and finally to the IR sensor located in the Cassette Holder. When the electronic command is given to find frame zero, the film loop is driven until an opaque strip placed across the zero frame of the loop, crosses under the curved fiber optic, breaking the IR light path. In the photograph of Figure 20, the opaque strip can



be seen just above the left-most delrin roller. An exploded parts drawing of the Film Cassette is shown in Figure B8 of Appendix B. A photograph of the assembled Right Optical Assembly, Cassette Holder and Cassette is shown in Figure 22.

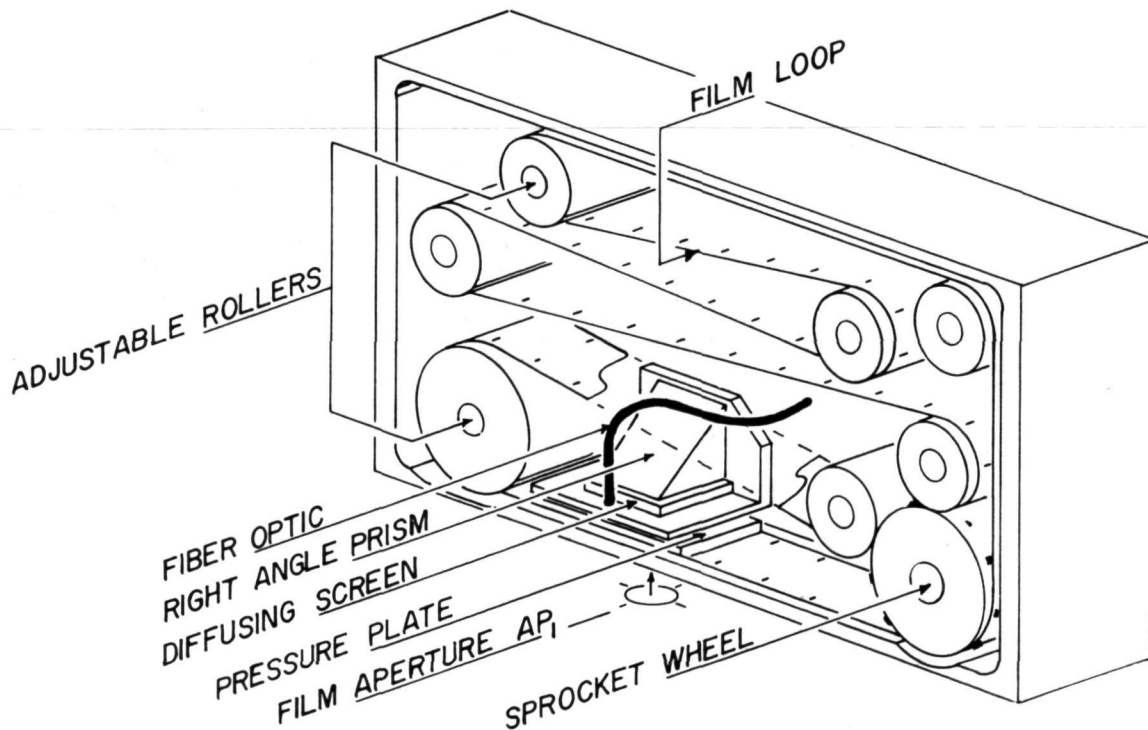


Figure 21. Drawing of the Right Film Cassette.

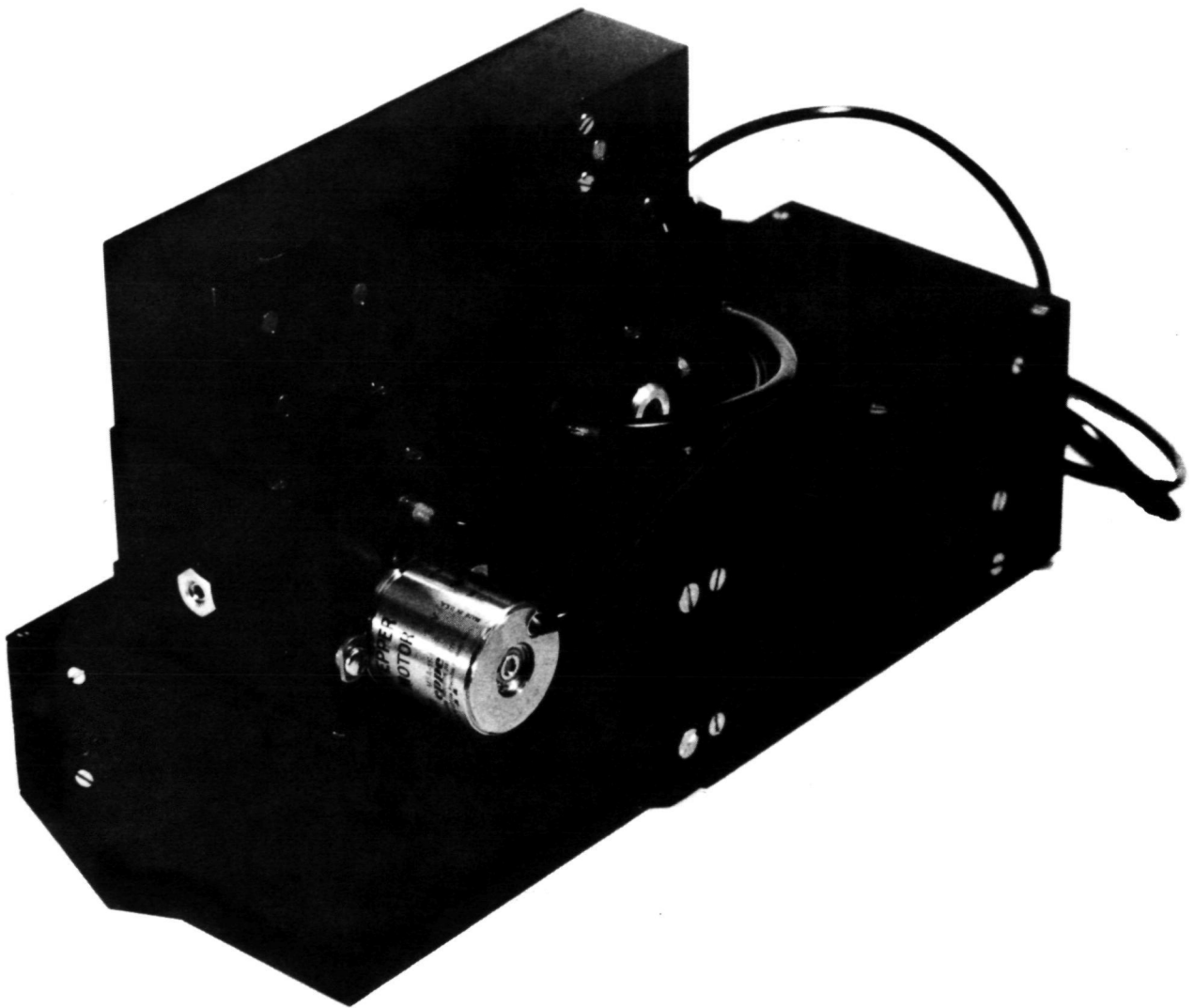


Figure 22. Photograph of Assembled Right Optical Assembly, Cassette Holder and Cassette.

## 5.0 THE HAPLOSCOPE ELECTRONIC CONTROL SYSTEM

### 5.1 General Functions

The Baylor Mark III Haploscope electronic control system performs 3 basic functions:

- 1) stimulus control,
- 2) subject response sensing,
- 3) test programming.

Stimulus control is accomplished by five servo subsystems designed to manipulate the major stimulus variables:

- 1) right film targets (including light source shutters),
- 2) left film targets (including light source shutters),
- 3) right stimulus to accommodation,
- 4) left stimulus to accommodation,
- 5) vergence.

Subject response sensing is performed by means of a five push button Subject Response Unit (see Figure 5), response indicators and appropriate computer interface circuitry.

Test programming, data storage and data recording functions are performed by the Haploscope computer system and its peripheral devices.

The electronics which perform these Haploscope functions can be operated in either a manual mode or a programmed mode. In the manual mode, stimulus control is achieved by manipulating switches provided for each of the stimulus variables. In this mode, the experimenter determines the testing sequence, controls the presentation of all test stimuli and manually records the subject responses. A provision is also made that allows the subject to control some of these stimuli directly by using his subject response buttons. In the programmed mode, the system computer controls the testing sequence according to pre-set testing paradigms. In this mode, registers controlled by the program take the place of the manual switches on a one for one basis. Under computer control, subject responses are automatically recorded and interactive testing paradigms in which each response of the patient determines the stimulus value presented on the subsequent trial are easily implemented.

## 5.2 Electronic Control System Organization

Figure 23 shows a block diagram of the Baylor Mark III Haploscope electronic control system.

1. The Haploscope. As indicated in Figure 23, the Haploscope houses the stepper motor drive circuits and position sensing devices for the 5 servo subsystems which provide the stimulus control.
2. The Subject Response Unit. This unit contains five push buttons, which serve as data inputs to the electronic control system (see Figure 5).
3. The Light Source. Four solenoids are contained in this unit to control the illumination of the right and left film targets and blank fields (see Figure 6).
4. The Haploscope Control Unit. As seen in Figure 23, the Haploscope Control Unit houses the manual controls, readouts and logic circuitry for the 5 servo subsystems and the Subject Response Unit. A photograph of the front panel of this portion of the system is shown in Figure 24. The lower portion of the panel is divided into 5 functional subsections (left target, right target, vergence, left accommodation and right accommodation, respectively). A digital panel meter is provided for each subsection to indicate frame number (film targets), vergence angle (to  $0.1^{\circ}$ ) and stimulus to accommodation (to 0.01 Diopter). Switches are provided for each to select a pre-set frame number, vergence or stimulus to accommodation. In manual mode, pushing the GO button on the left of each subsection panel drives the respective servo system to the pre-set value. A manual drive switch in the lower middle of each subsection panel permits continuous driving of each servo at whatever speed is selected by the SPEED switch on the right. For the right and left target subsections, the center switch on the bottom of the panel provides manual control of the light source shutters. The switch on the lower right of each panel can be used to manually ZERO each film loop. The upper part of the Haploscope Control Unit Panel contains a readout of the subject's responses (in this photograph CLEAR, meaning no response). The switch to the right of the readout permits the use of the Subject Response Unit as a manual control for the right and left accommodation or vergence angle stimulus variables.

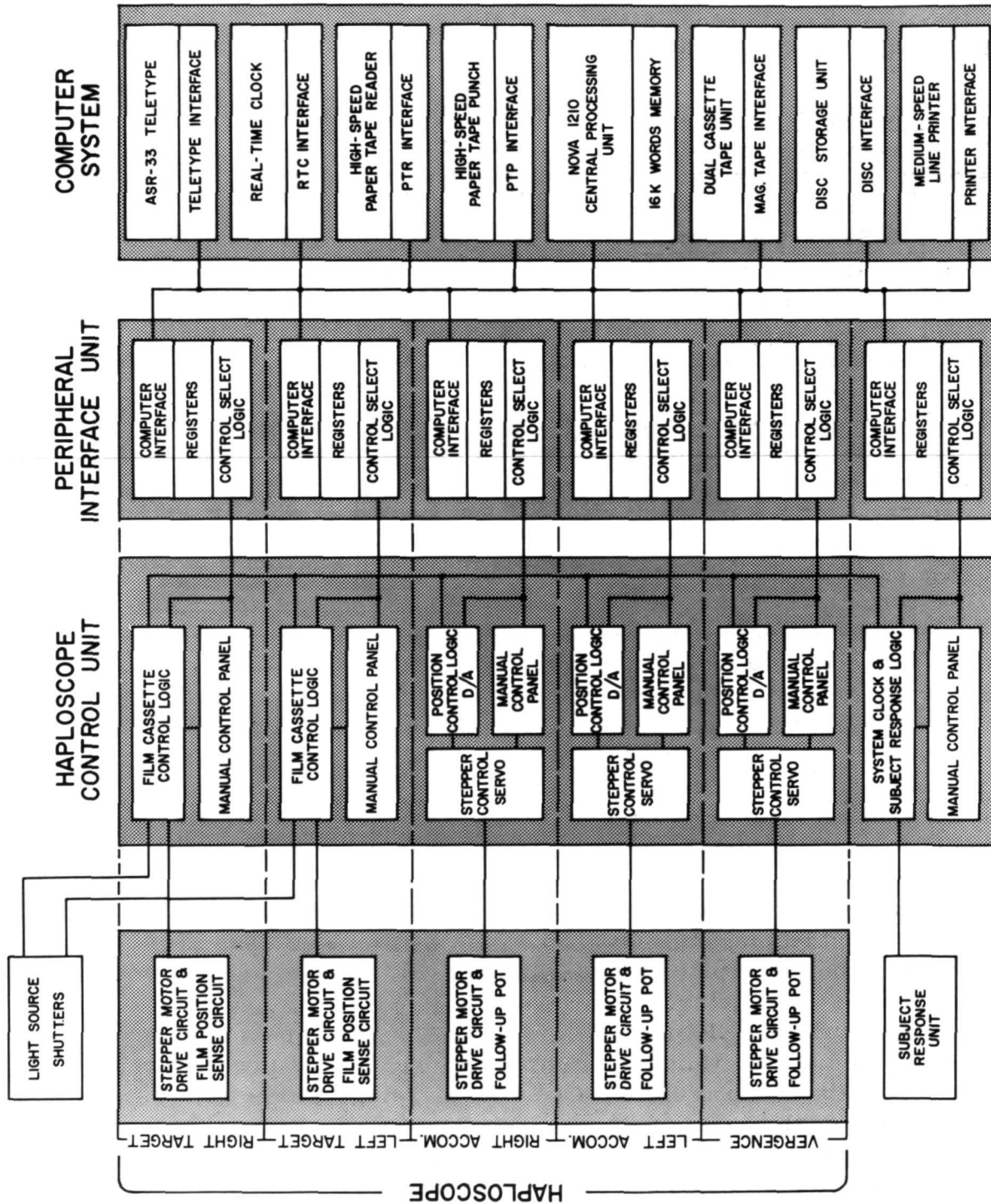


Figure 23. Block Diagram of the Baylor Mark III Haploscope Electronic Control System.

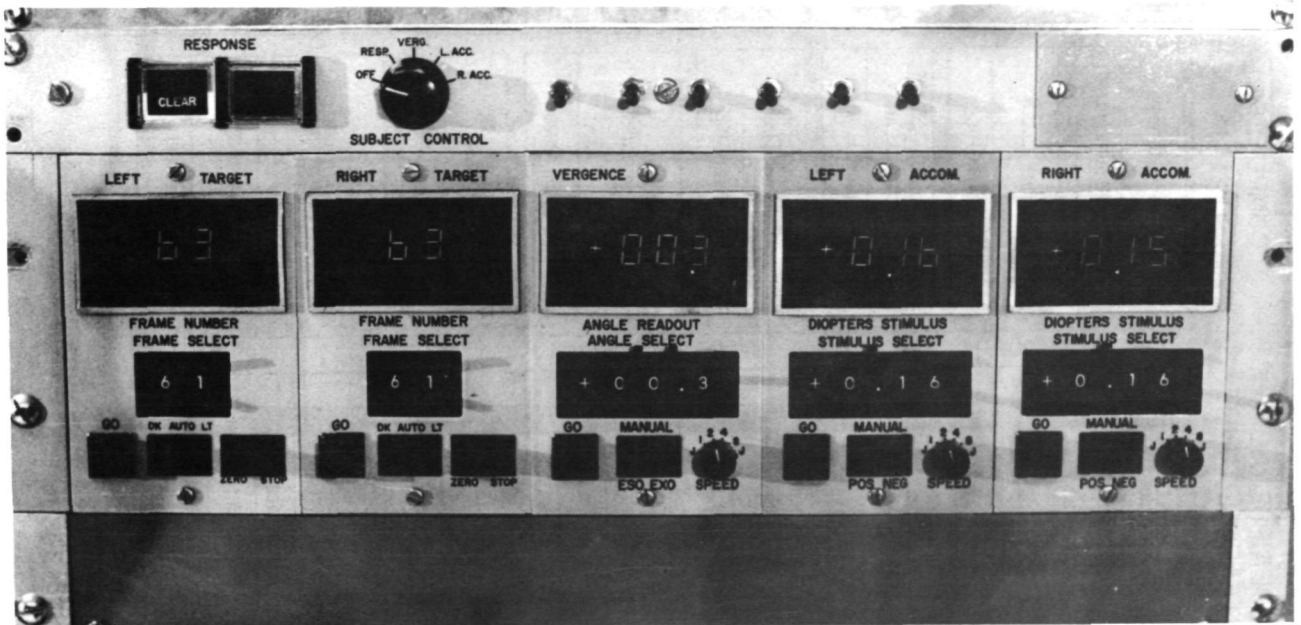


Figure 24. Photograph of the Haploscope Control Unit.

5. The Peripheral Interface Unit. As shown in the diagram of Figure 23, this unit houses the control select logic, registers and computer interface circuitry for the 5 servo systems and the subject response system. A photograph of this unit with the front panel removed is shown in Figure 25. A printed circuit mother-board in the back of the unit receives up to 11 daughter-boards and interconnects with the computer I/O Bus. Each daughter-board contains the digital circuitry for one of the servo subsystems. Additional space for future expansion of the system is provided.

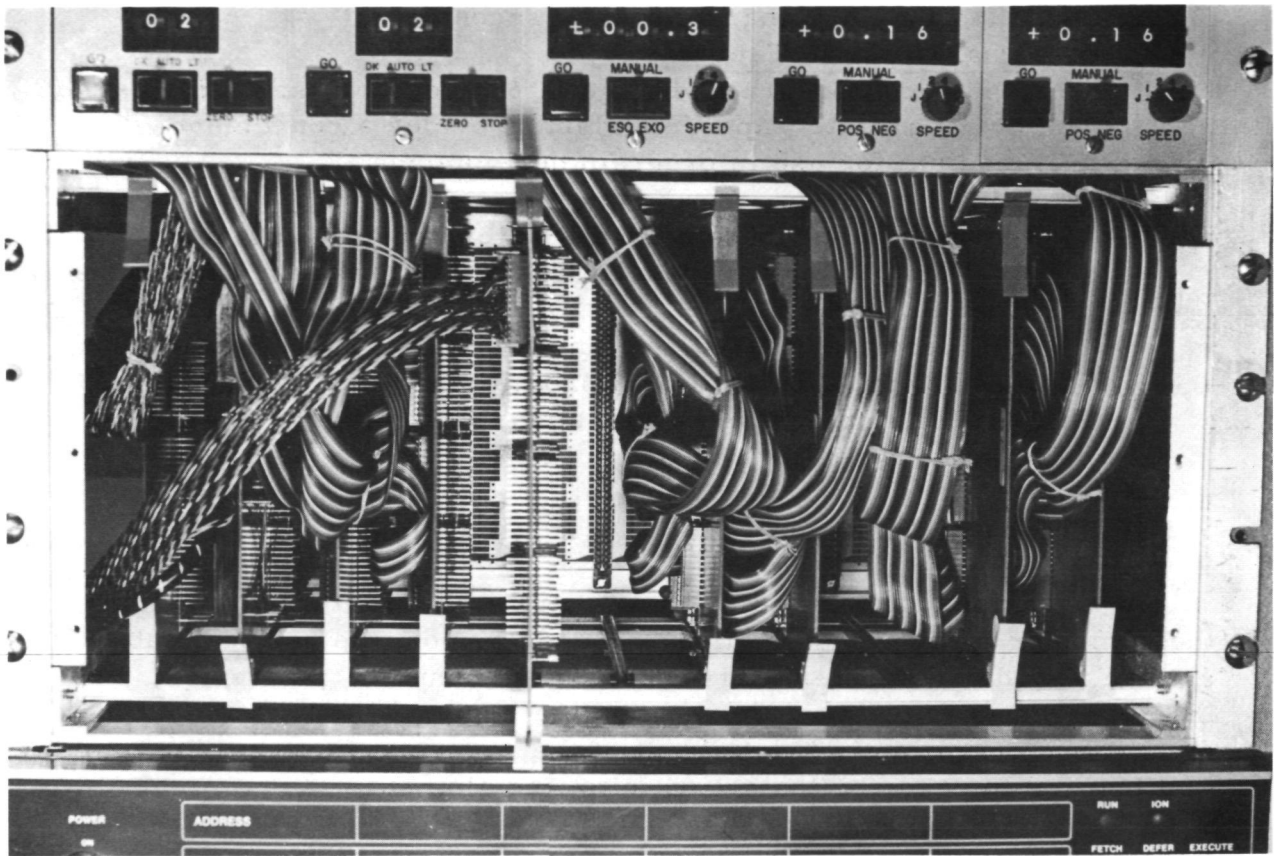


Figure 25. Photograph of the Peripheral Interface Unit with the Front Panel Removed.

6. The Computer. A NOVA 1210 is used as the system controller and contains 16 K words of core, the teletype interface, the Real Time Clock interface and Real Time Clock, and the High Speed Paper Tape Reader and Punch interfaces. The I/O Bus is made available to the system via a 100 pin connector on the back of the NOVA 1210.

7. The Computer Peripheral Devices

a. Teletype

An ASR33 Teletype is used as a keyboard entry/printer for the system.

b. High Speed Paper Tape Reader

A 500 character per second Paper Tape Reader connects to the computer interface located within the NOVA 1210.



- c. High Speed Paper Tape Punch  
The Punch is connected to the interface in the 1210 and punches at 60 characters per second.
- d. Dual Cassette Tape  
Additional program storage is provided by use of the dual Cassette Tape Unit which provides a convenient medium for use in program development.
- e. Line Printer  
A 135 line per minute Line Printer provides fast hard-copy output for test results as well as program listings.
- f. Disc System  
The single cartridge, moving head Disc Drive System is used to provide additional program and data storage.

Figure 7 is a photograph of the electronic control system mounted in two relay racks.

### 5.3 Theory of Operation

In each of the subsystems, operation can be initiated by either the computer or by manual action, depending upon whether that subsystem is under computer control or manual control. Therefore, in subsequent discussions, the source of a command will not be given since operation is independent of the source. The term "control" will be used to describe the action initiating element.

### 5.4 Stimulus Control Subsystems

#### 5.4.1 The Film Cassette Control Subsystem

The left and right film drives are electrically identical, independent, open loop subsystems. Each consists of the following elements:

1. Computer Interface
2. Manual Control Switches
3. Haploscope Control Logic Card
4. Stepper Motor Drive Circuit
5. Stepper Motor
6. Frame Zero Detector
7. On Frame Detector
8. Cassette Mounted Interlock Switch
9. Light Source Shutters

The function of the subsystems is to allow the control to select any of the targets to be shown to the subject, and to control the light



source shutters. The following controls allow this to be accomplished (see Figure 24):

1. FRAME SELECT Data (00-99)
2. GO Command
3. ZERO/STOP Command
4. Target Indicator (00-99)

The system operation is as follows:

1. A film cassette is mounted in the Cassette Holder.
2. A zero command is issued. The film advances to frame zero and stops when:
  - a. the Frame Zero Sensor detects the frame zero band,
  - b. the On Frame Sensor indicates that the stepper motor has stepped to the beginning of a frame.
3. At this time, the frame indicator will reset to indicate frame zero (00) with no error. An error is indicated by a lamp in the GO switch. The computer can read this indicator. If an error exists, the fault could be:
  - a. the cassette Mounted Interlock Switch indicates that no cassette is present,
  - b. the On Frame Sensor indicates that the frame is not properly positioned in the Cassette Holder.If the cassette is firmly mounted, re-zeroing the film should remove the error. Since the operation is open loop, proper target selection can only be accomplished if operation begins from a known position (i.e. frame zero).
4. Any frame may be selected now by entering the desired FRAME SELECT Data into the target control logic and issuing a GO Command. The film will move until the target indicator matches the FRAME SELECT Data. The direction of movement depends upon whether the selected frame number is greater or less than the indicated number. The indicated number represents the state of a two-decade up/down counter whose counting direction is selected by comparing the FRAME SELECT Data with the counter state. When the two agree, the counting stops. For each change in the counter's units decade, eight pulses are sent to the stepper motor driver causing the motor to move the film one frame.

#### 5.4.2 Light Source Shutter Control

Light can reach each of the subject's eyes either by illuminating the target field or the blank field. A third alternative is a totally dark field with neither field illuminated. The shutter control is accomplished by solenoids located in front of the fiber optic bundle associated with each form of illumination. The light modes are then:

- |                |   |
|----------------|---|
| 1. Dark (DK)   | - Both off  |
| 2. Light (LT)  | - Blank Field/No target   |
| 3. AUTO (AUTO) | - Target viewed when film is not moving<br>Blank field viewed when film is moving |

#### 5.4.3 The Vergence Angle, Left and Right Stimulus to Accommodation Subsystems.

The electronics for vergence angle and for left and right stimulus to accommodation are three independent but functionally identical units. All three are feedback controlled subsystems which differ electrically only in terms of their scale factors. Each consists of the following elements:

1. Computer Interface Card
2. Manual Control Switches
3. Haploscope Control / BCD/Analog Card
4. Haploscope Control / Stepper Control Servo Card
5. Stepper Motor Drive Circuit
6. Stepper Motor
7. Follow-up Potentiometer
8. Limit Switches

The function of the subsystems is to allow the control to select a vergence angle or an accommodative stimulus and cause the system to move to that position. In addition, either the control or the subject (via the subject response inputs) can cause the position of these systems to change in a continuous manner as required for certain test procedures and to readout the position at any point in time.

The system controls allowing these to be accomplished are:

1. ANGLE or STIMULUS SELECT Data
2. GO Command
3. Position Indicator (3 digits)
4. MANUAL Positioning (ESO/EXO; plus/minus)
5. SPEED SELECT Data (JOG, 1, 2, 4, 8)

To move to a desired pre-set position, the system operates as follows:

1. Set the ANGLE or STIMULUS SELECT Data
2. Execute a GO Command

The red light in the GO switch illuminates and the servo moves toward the selected position. When the servo nulls, the light goes out and the position indicator agrees with the position select data, plus or minus one least significant digit. If the light stays on after physical motion stops, the mechanism may have moved against a limit switch.

An alternative way of moving, independent of the position select data, is by pressing the MANUAL (ESO/EXO) switch in the desired direction with the SPEED SELECT Data set as required. The MANUAL switches are selectively paralleled by the subject control unit, according to the subject response mode data in effect.

The servo subsystems of the vergence and right and left accommodation controls are organized as shown in Figure 26.

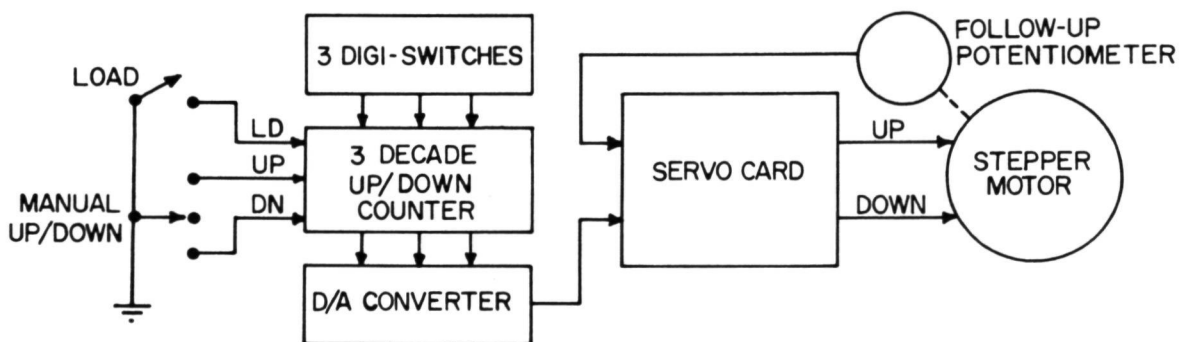


Figure 26. Diagram of a Typical Stimulus Control Servo Circuit.

The 3 decade counter can be loaded with the 3 digit select switches by pressing GO, or it can count up or down by use of the MANUAL switch. The analog voltage proportional to the contents of the counter is compared to the follow-up potentiometer and "step clockwise" or "step counter clockwise" pulses are fed to the stepper motor until the feedback voltage agrees with the D/A voltage to within

a "no step" window, which is a function of the gain of the servo comparison amplifier.

#### 5.5 The Subject Response Subsystem

The Subject Response Subsystem consists of the following:

1. Computer Interface Card
2. Haploscope Subject Response/System Clock Card
3. Subject Response Control Panel
4. Subject Response Unit

As previously discussed, it is useful to include the subject within the test loop in the course of automated testing. The subject responses are input by means of the Subject Response Unit. These buttons are debounced and available for sensing on the computer interface card. The responses are also indicated on the Haploscope Control Unit front panel. These indicators can be manually reset or cleared by program control.

The subject responses can also be used to alter system servo position (vergence angle and stimulus to accommodation) according to subject response control data, which is either switch selected or program selected.

The modes are as follows (see Figure 24):

- |                                 |  |
|---------------------------------|--|
| 1. OFF (OFF)                    | - No servo control from subject response unit (all indicators cleared)   |
| 2. Response (RESP.)             | - No servo control (indicators display buttons pressed)  |
| 3. Vergence (VERG.)             | - Left and right subject response buttons control vergence movement Left (EXO), Right (ESO) (indicators display button pressed)                      |
| 4. Right Accommodation (R.ACC.) | - Top and bottom subject response buttons control right accommodation servo movement; top (plus) bottom (minus); (indicators display button pressed) |
| 5. Left Accommodation (LT.ACC.) | - Same as Rt. Accom., except left  |

## 5.6 The Computer System

The computer system is set up both to provide control for the Haploscope and to allow for efficient and convenient software development. Each of the various computer interfaces has its own hardware device code to allow for individual program control. Some of the interfaces allow for programmed interrupts, so that the program can operate more efficiently in a Real Time Mode of operation. The Real Time Clock Unit allows precise event timing (10 millisecond resolution used) as well as maintaining the Time of Day.

The software is of three basic types:

1. Operating System Software
2. Systems Support Software
3. Applications Software

### 5.6.1 Operating System Software

The Operating System software is written entirely in Assembly Language and consists of a small monitor which allocates control of various tasks requiring attention to the system interrupt handler, and the I/O peripheral drivers. The system operating philosophy is to let various tasks have complete control of the entire system on a sequential basis. Provisions are made so that a task may exit and request reentrancy on the following conditions:

1. Response requested - The task exits and is reentered when a response is made by an operator (i.e., End of Message button pressed on the teletype).
2. Rescan requested - The task gives up control to the next sequential active task and is reentered when it is its turn again. This occurs normally at an interval on the order of a millisecond, depending upon the number of active tasks.
3. Programmed Delay - The task requests reentrancy after a fixed delay which may range from 10 milliseconds to 655.35 seconds.

Since the various active tasks are effectively multiplexed, the system is called TMOS (Task Multiplexed Operating System). TMOS is one of the simplest methods of achieving a multiprogramming or Real Time mode of operation that can be implemented. It has the advantage of allowing all the systems support software to be non-reentrant. It is essentially a rudimentary time sharing system which will allow system expansion to permit two or more types of tests (i.e., Haploscope and Visual Fields) to occur simultaneously.

### 5.6.2 System Support Software

The system support software is a group of small subroutines that can be used by the applications software for such things as code conversion (i. e. , Binary to ASCII), arithmetic operations (multiply, random number generation, etc.), message handling routines, etc. These routines need not be reentrant since they are only used by the applications software task and only one task can have control at a time. Therefore no support routine can be interrupted in the middle and used by another task, and then be reentered by the first task.

### 5.6.3 Applications Software

Applications software is written to perform a particular task requested by the operator. The tasks include such system functions as setting the time and date or printing the time and date upon request, examining core and performing a requested test paradigm such as visual acuity, stereopsis, etc. The applications software tasks will continue to be written as new test paradigms are developed and implemented.

## 6.0 TESTING PROCEDURES

The interactive testing capability in which the subject's responses determine the nature of the subsequent trial is an important aspect of the Haploscope. In a sense, a system with this capability is the equivalent of an intelligent human operator who interprets each response a subject makes and decides on the basis of that response what stimulus to present to the subject on the next trial. Some inherent advantages of the computerized decision making process over the knowledgeable operator are that it makes consistent judgments, makes them very rapidly and executes the stimulus adjustments needed for the next trial more rapidly and possibly more accurately than a human operator.

Three visual test programs which utilize the interactive concept are currently employed in the Baylor Mark III Haploscope System. These tests of visual acuity, stereopsis and phoria are forerunners of additional vision tests which will utilize the same basic concept.

### 6.1 Visual Acuity Testing Program

As noted previously (Section 2.3.2), the automated visual acuity testing paradigm employed is similar to that utilized by Crossman et al. (1970). The subject is shown a series of acuity targets starting with one that is well above threshold (e.g. 20/200). He responds by pressing one of four buttons corresponding to the position of some aspect of the acuity target pattern (i.e., the location of the gap in a Landolt C or of the grating in a checkerboard acuity target). Each time the subject makes a correct discrimination he is subsequently presented with a smaller (higher acuity) target. If he is wrong, he subsequently receives a larger (lower acuity) target. In the Haploscope paradigm, 14 levels of acuity targets are available ranging from 20/200 to 20/10. In order to approach threshold level rapidly, the program is set up so that an increment of two levels occurs after each correct response (Mode A) until the first error occurs (Mode B). Thereafter, only single level increments or decrements occur. The testing continues until a pre-set number of trials occurs at any given acuity level.

Figure 27 shows a flow chart of the basic elements of the acuity test as performed in the Baylor Mark III Haploscope. The stimulus to accommodation and vergence angle of the Haploscope can be automatically pre-set (Box 1 in Figure 27), at a 6 meter equivalent (stimulus to accommodation = +.16D, vergence angle = +.3° ESO), or at any position within the range of the instrument.

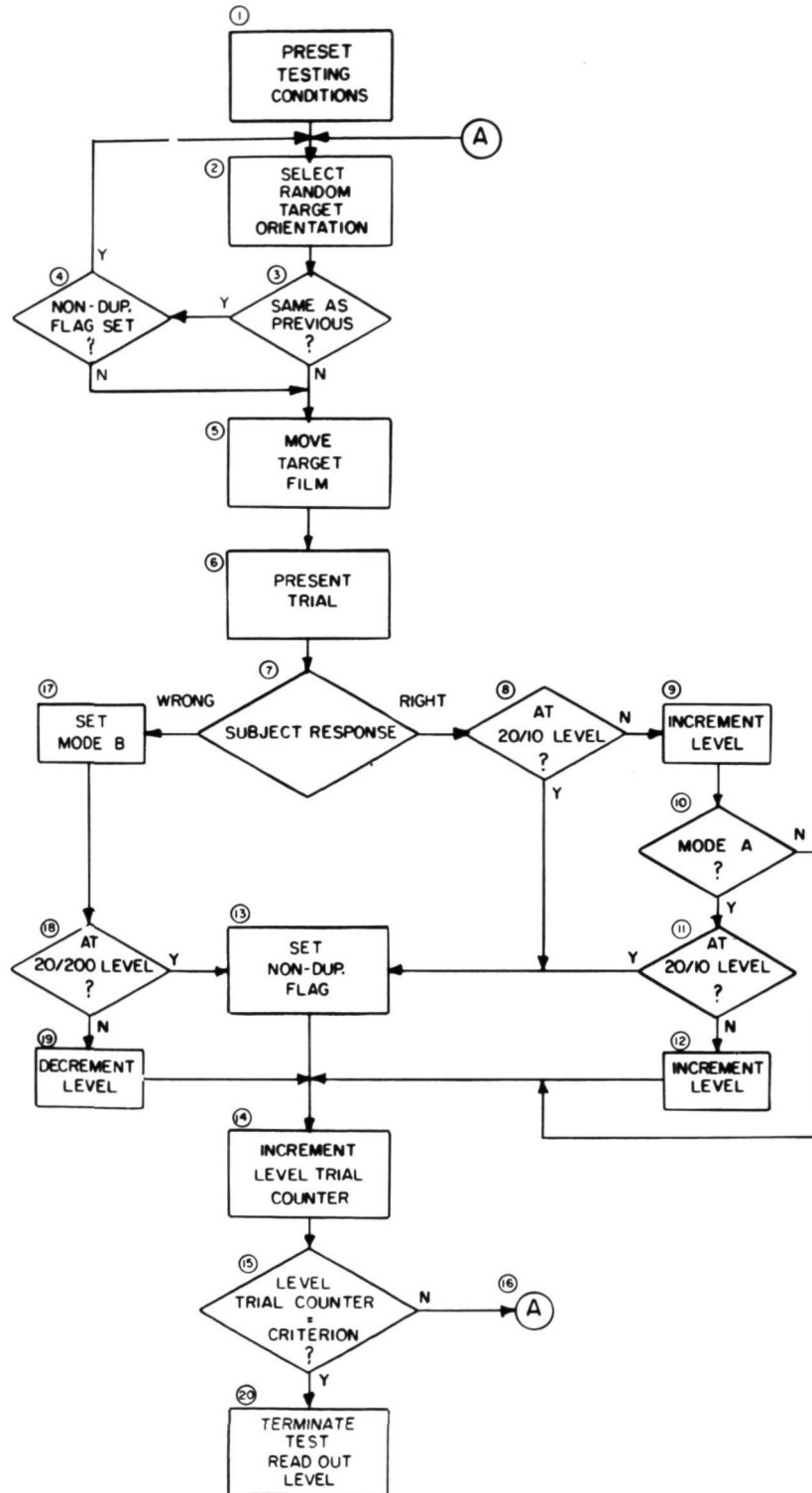


Figure 27. Drawing of the Flow Chart of the Acuity Testing Program.



The orientation of the visual acuity target is randomly determined (Box 2, Boxes 3 and 4 to be explained later), the target film loop moved to the appropriate frame (Box 5) and the visual stimulus presented (Box 6). If the subject's response (Box 7) is correct, the program first checks to make sure the subject is not already at the highest available acuity level (Box 8) and then increments the acuity level (Box 9). As long as the subject continues to make no errors (in Mode A, Box 10), the acuity level is incremented (Box 12) until the 20/10 level is reached (Box 11). At this point, the program increments a "level trial counter" associated with the level of the trial the subject is about to receive (Box 14). When the incremented number in this counter equals a pre-set criterion number, the test is terminated and the level read out as the subject's threshold. As long as the "level trial counter" does not equal the criterion, then the program goes through A (Box 16) back to the top (Box 2) to present the next stimulus.

When the subject makes an incorrect response (Box 7), Mode B is set (Box 17), a check is made to see if the level counter is at the 20/200 level (Box 18) and, if not, the acuity level is decremented. As before, the "level trial counter" for the new level is incremented and tested against the criterion number. If at any time the acuity level reaches either end of the target scale, e.g. 20/200 (Box 18), or 20/10 (Boxes 8 and 11), a non-dup flag is set (Box 13), which insures that the subsequent stimulus at the same level will have a different orientation (Boxes 3 and 4).

The end point of this visual acuity paradigm is based on achieving an arbitrary number of trials at any given acuity level. This is just one of several types of criteria which could be used (e.g. arbitrary number of correct trials at any given level, etc.). On the basis of experience gained in using this testing paradigm, it is apparent that the selection of one criterion over another is arbitrary and yields little difference in final threshold level. The same observation has been made by Crossman et al. (1970) using a similar paradigm.

Figure 28 is an acuity test computer printout obtained with the Haploscope System. As can be seen, all stimulus parameters, date, time and subject identification are recorded. The digits that appear in the column just below the "Right Accom." notation are the film frame number of the first acuity target used (06), the denominator of the Snellen value of the target (200 = 20/200), the actual orientation of the gap of the Landolt C target (L), and the subject's response (L). As shown, the final acuity level for this subject was 20/10. The criterion count for this test was 8, although a criterion count of 4 has been found to suffice for most testing. Presumably, test reliability is improved when a higher criterion count is employed.

ACUITY TEST                      SUBJECT 111

EYE BEING TESTED---RIGHT

END CRITERION COUNT = 00  
09:33:32 AM 04-16-75

VERGENCE        = +00.3  
LEFT ACCOM = +0.16  
RIGHT ACCOM = +0.14

06-200-L<L>  
14-125-L<L>  
20-080-R<R>  
29-050-D<D>  
37-030-D<D>  
46-020-L<L>  
53-013-D<U>  
50-016-L<L>  
53-013-D<D>  
59-010-U<L>  
54-013-L<L>  
58-010-L<L>  
56-010-R<R>  
59-010-U<R>  
55-013-U<U>  
57-010-D<R>  
52-013-R<R>  
57-010-D<D>  
58-010-L<R>  
52-013-R<R>

FINAL ACUITY LEVEL 20/010

PROGRAM TERMINATED @ 09:34:29 AM

TEST DURATION = 00:00:54

Figure 28. Acuity Test Printout.

## 6.2 Stereopsis Testing Program

The testing of stereopsis or depth perception is carried out on the Haploscope in an almost identical fashion to the acuity testing. The target imagery used for stereopsis testing consists of four small black on white circles arranged in a diamond pattern inside of a diamond shape black on white frame (see Appendix A). The subject's task is to detect the circle that appears to be at a different depth from the remaining circles, and to press the button on the Response Unit that corresponds to that circle. Differing degrees of target disparity for any one of the 4 circles are achieved by photographing a series of target patterns in which that circle is laterally displaced by precise amounts, producing a spatial disparity between the target seen by one eye and the target seen by the other. Individual images of the targets are provided on the Haploscope film loops with disparities ranging from 300" of arc to 5" of arc. A description of the photographic process involved in producing the target films is provided in Appendix A. As in the acuity testing paradigm, each time the subject makes a correct response he subsequently receives a more difficult target (less disparity) and vice versa. A capability for providing crossed, uncrossed or mixed (crossed and uncrossed) disparities is provided in the stereopsis test.

Figure 29 is a computer printout of a typical stereopsis test carried out on the Baylor Mark III Haploscope. The figures in the column that appears below the "Right Accom." notation represents the film frame numbers (88, 88) used in each trial, the disparity of the target combination (+125) in seconds of arc, the position of the disparate circle (D) and the subject's responses (D). The "+" symbol before the disparity designation indicates crossed disparity ("-" would indicate uncrossed disparity). In this test only crossed disparities were used. The end criterion count was set at 6, yielding a threshold disparity of 10 seconds of arc.

## 6.3 Lateral Phoria Testing Program

The automated lateral phoria testing program utilizes an interactive procedure with a different test paradigm than the visual acuity and stereopsis procedures. In the lateral phoria test, the subject views a horizontal row of 7 dots with the numbers 3, 2, 1, 0, 1, 2, 3 above each respective dot in the upper field of view of one eye. Both dots and numbers are white on a black background and are seen continuously throughout the test. With the other eye, the subject sees a vertical white arrow on a black background the lower half of the field. This arrow is flashed for a constant duration (e.g. 0.5 seconds) once at the start of each trial. For each trial, the subject's task is to indicate with the appropriate

STEREOPSIS TEST

SUBJECT # 111

END CRITERION COUNT = 06

09:34:55 AM 04-16-75

VERGENCE = +00.3

LEFT ACCOM = +0.16

RIGHT ACCOM = +0.14

80.80 +125" D<D>  
80.72 +115" D<D>  
80.64 +105" D<D>  
76.80 +095" D<D>  
79.75 +085" U<D>  
78.78 +090" L<L>  
79.75 +085" U<U>  
77.69 +080" R<R>  
76.64 +075" D<D>  
78.63 +070" L<L>  
73.77 +065" R<R>  
73.73 +060" R<R>  
74.70 +055" L<L>  
75.67 +050" U<U>  
72.63 +045" D<D>  
70.74 +040" L<L>  
70.70 +035" L<L>  
68.64 +030" D<D>  
68.63 +025" D<D>  
64.68 +020" D<D>  
66.66 +015" L<L>  
66.63 +010" L<R>  
64.64 +015" D<L>  
65.69 +020" R<R>  
65.65 +015" R<R>  
66.63 +010" L<U>  
65.65 +015" R<R>  
66.63 +010" L<R>  
65.65 +015" R<R>  
67.63 +010" U<U>  
63.66 +005" L<L>  
63.64 +005" D<D>  
63.67 +005" U<L>  
67.63 +010" U<U>  
63.65 +005" R<R>  
63.64 +005" D<L>

FINAL DISPARITY LEVEL 010"

PROGRAM TERMINATED @ 09:37:33 AM

TEST DURATION = 00:02:36

Figure 29. Stereopsis Test Printout

response button whether the arrow appeared: 1) to the right of the center dot (press right button); 2) aligned with the center dot (press center button); or to the left of the center dot (press left button). Except for the row of numbers and dots in one eye, and the flashed arrow in the other eye, both fields are totally black and contain no fusional cues.

Figure 30 is a flow chart of the phoria test procedure. At the start of the test, the stimulus to accommodation and the vergence angle are pre-set (Box 1). The row of numbers and dots is presented and the arrow flashed (Box 2). If the subject responds that the arrow and central dot are aligned, e.g. X (Box 3), an "aligned response counter" is incremented (Box 4), and the number in this counter is tested against an "Aligned criterion number." (This is the number of consecutive "aligned" responses needed to terminate the test.) If the counter number equals the "aligned criterion number," the test would be terminated, the final vergence angle would be adjusted for accommodative convergence to yield actual phoria and both values would be read out. If the "aligned criterion number" has not been met, the program goes to A (Box 17), and another trial is initiated (Box 2).

If the subject responds with either an R or L, the program checks first to see if the response was the same as on the previous trial (Boxes 6 and 7). If so, the program changes the vergence angle in the appropriate direction (Box 14 or 15) by an increment  $\Delta/Y$  degrees (where  $Y = 1$ ). If the subject's response had been different from the previous response (Boxes 6 and 7), the program would check to see whether the counter that keeps track of the number of reversals in the response sequence is equal to a "reversal criterion count" (Boxes 8 and 9). If this is the case, the test terminates, the final vergence angle is read out and the actual phoria is calculated and read out. If this is not the case, the reversal counter is incremented (Boxes 10 and 11),  $Y$  becomes 2 times the number in the reversal counter, (Boxes 12 and 13) and the vergence is moved in the appropriate direction by an increment of  $\Delta/Y$  degrees (Boxes 14 and 15). In other words, each time the arrow crosses the central dot, the subject reverses his response (e.g. from L to R or R to L) and the size of all subsequent vergence angle increments is halved. The test continues until the criterion number of response reversals occurs (by which time the vergence angle increment has become very small), or until a pre-set number of consecutive "aligned" responses occur.

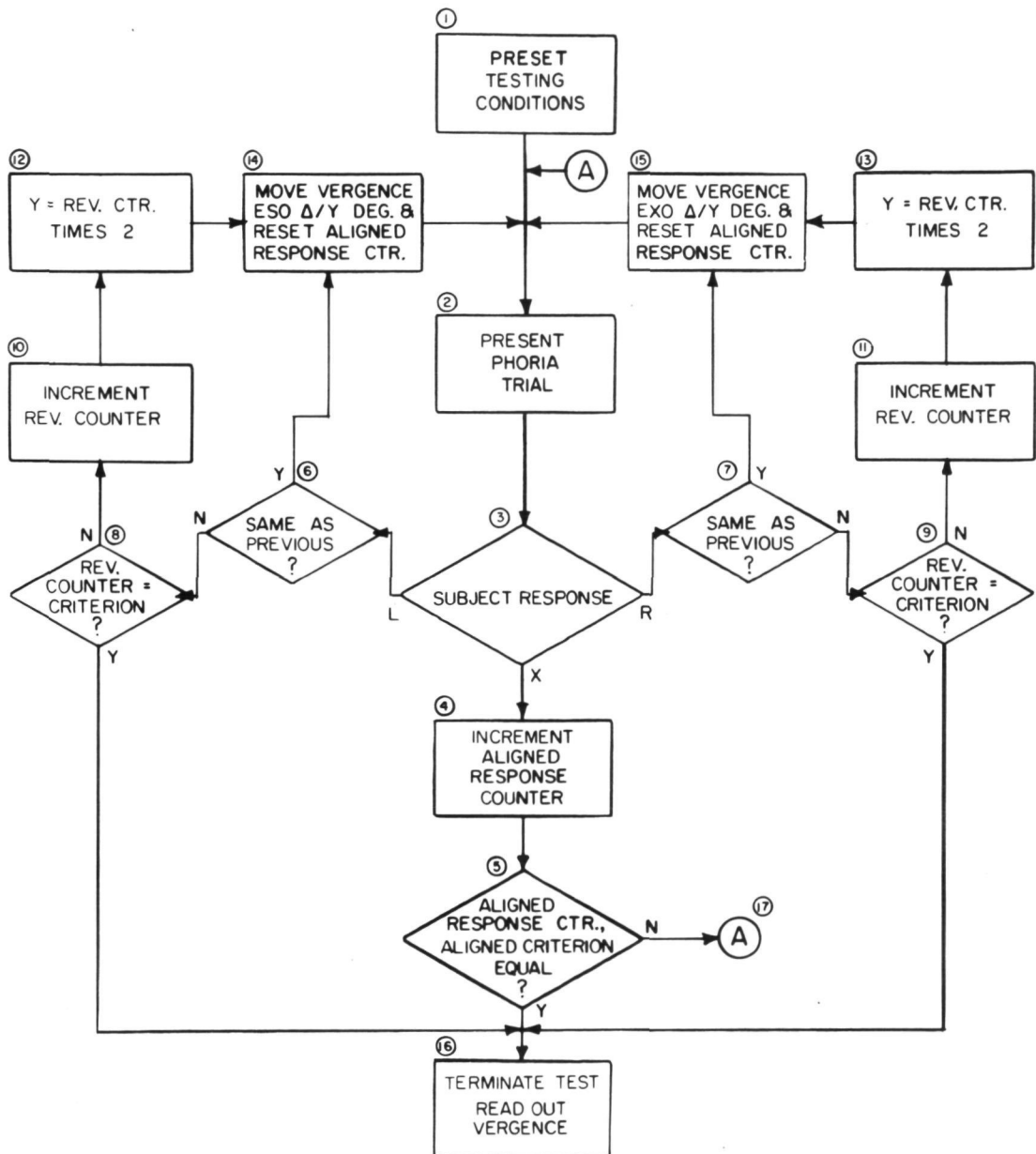


Figure 30. Drawing of the Flow Chart of the Lateral Phoria Testing Program.

In spite of the complexity of the description of the test paradigm, subject instructions are simple and testing time is usually one-half to one minute. Figure 31 shows a sample lateral phoria test printout. The test was performed with an "aligned criterion" of 3, and a "reversal criterion" of 8. The left and right stimuli to accommodation are set to values that simulate a 6 meter test distance. The vergence setting and the +5.00 that appears below the "Right Accommod." notation indicates that the first trial was presented with the vergence angle at +05.0°. The <R> ; <L> or <X> symbols indicate the subject's response on each trial, with the test terminating after 8 reversals. When the final vergence setting (+00.2°) is adjusted for the pre-existing accommodative convergence (+00.3°), the calculated phoria becomes -00.2° (EXO).

#### 6.4. Other Tests

With additional research it will be possible to utilize the principles incorporated in the acuity, stereopsis and lateral phoria tests to perform many other vision tests. For example, only the stimulus material of the lateral phoria procedure need be modified in order to test fixation disparity. Cyclophoria could easily be implemented by presenting a fixed stimulus in one eye similar to —○— and a series of stimuli in the other eye with differing amounts of stimulus rotation, i.e.  $\Theta$ ,  $\emptyset$ ,  $\ominus$ , and so forth. Work is currently underway to develop test paradigms for these measures in addition to vertical phoria and suppression.

LATERAL PHORIA TEST

SUBJECT # 111

ALIGNED CRITERION = 3  
REVERSAL CRITERION COUNT = 8  
04:38:06 PM 04-16-75

VERGENCE = +05.0  
LEFT ACCOM = +0.15  
RIGHT ACCOM = +0.14

+05.0 <R>  
+03.4 <R>  
+01.8 <R>  
+00.3 <R>  
-01.3 <L>  
-00.6 <L>  
+00.0 <R>  
+00.0 <L>  
-00.2 <X>  
+00.0 <L>  
+00.1 <R>  
+00.2 <L>  
+00.1 <R>  
+00.2 <L>  
+00.1 <X>  
+00.2 <X>  
+00.2 <L>  
+00.2 <R>

FINAL VERGENCE SETTING = +00.2 DEG.

CALCULATED PHORIA = -00.2 DEG. (EXO)

PROGRAM TERMINATED @ 04:38:37 PM

TEST DURATION = 00:00:38

Figure 31. Lateral Phoria Test Printout.



## 7.0 HAPLOSCOPE APPLICATIONS

The Baylor Mark III Haploscope was designed specifically to test the visual function of astronauts during spaceflight. The design of the instrument for these purposes, however, does not preclude its application in other areas. This section is written in the belief that the needs exists for improve methods of testing visual function both in vision research and in clinical ophthalmic care. The intent here is to describe some of these needs and to speculate upon the role that the Haploscope System or some future version of the instrument could play in the fulfillment of these needs.

### 7.1 Environmental and Physiological Factors Affecting Visual Performance

It is well known that the anatomical and physiological state of the visual system often reflects the status of the function of the entire organism. The retina has the highest respiration rate of any body tissue, and hence manifests the effects of anoxia more quickly than in any other part of the body. Eye muscle function reflects the tonus of the general body musculature. Intraocular pressure is altered by systemic blood osmolarity. Moreover, a broad range of systemic diseases and dysfunctions have ocular manifestations.

The list of examples could continue, but the point is that sensitive, quantitative measures of visual function and visual anatomy are potentially useful tools for the assessment of the effect of a wide variety of environmental factors upon man. Aside from such obvious and convenient measures as visual acuity, however, few visual indicators have been utilized for this purpose. This is primarily because convenient, quantitative means for measuring the more subtle aspects of visual function simply have not been available outside of the well-equipped eye clinic, or the vision research laboratory.

If one wanted to quantify fully the effects of the hyperbaric under-sea chamber environment upon vision, for example, only two real alternatives are available. The experimenter could employ some version of an industrial screening type tester. But, while several industrial screening type devices (e.g. the Bausch and Lomb Orthorater, the A.O. Sightscreeener, and the Titmus Vision Tester) are available and are reasonably convenient to use, they are capable of measuring a very limited number of visual parameters in only a grossly quantitative manner. On the other hand, the experimenter could bring a trained clinician into the test chamber, but this is obviously impractical. Moreover, manually administered subjective tests are difficult to

standardize and may be more affected by experimenter variables than by the independent variable under study.

The major contributions of the Haploscope in situations such as this are its ability to quantify the more subtle aspects of visual function, its programmability and its portability. Because the Haploscope system is essentially self-administering, the necessity of utilizing a clinician or a trained vision experimenter is eliminated. Moreover, because the tests paradigms eliminate the possibility of memorization, repeated measurements over extended time periods are not contaminated by learning variables. Although the portability of the electronics used with the present version of the Haploscope is limited, other versions could be constructed in which the entire electronics package is no more than 6 to 8 cubic feet in size. In its optimal form as a stand-alone instrument, the entire Haploscope could be easily transported and operated in a small room, a bus, car or an aircraft. Based on these capabilities, the Haploscope could be used to monitor or measure visual performance in a wide range of situations for many purposes, such as the following:

- a. to determine the effects of hyper- or hypobaric environments on vision,
- b. to determine the effect of circadian rhythm changes on vision (i.e. carried on board aircraft which passes through several times zones),
- c. to determine the effects of work schedules upon FAA Air Traffic Controllers or other vision intensive professions (i.e. located next to work stations and available for testing 24 hours a day).

It is also clear that for a still broader range of visual test capabilities the entire NVTs could prove extremely valuable in the same kinds of testing situations for which the Haploscope system is so well suited.

## 7.2 The Measurement of Visual Function

The ability to evaluate the function and anatomy of the human body is fundamental to our knowledge of how it works, and to our ability to diagnose and treat its dysfunctions. Much of our recent knowledge about visual physiology has resulted from the availability of new measurement devices (e.g. the oscilloscope, the computer of average transients) and new measurement techniques (e.g. spectral microdensitometry). The Haploscope System could prove extremely useful as a vehicle for expanding our knowledge of visual system function by improving the quality of psychophysical data obtained in vision research and by expanding the vision testing capabilities of the ophthalmic clinician.

### 7.2.1 Visual Psychophysics and Clinical Testing

A great deal of research has been performed in the past to explore the clinical value of certain aspects of binocular visual function, such as the AC/A ratio, as indicators of the effects of age, visual training and even visual fatigue. In the past, this research has been limited largely by the degree of stimulus control possible, and by the logistics of manual test administration.

Both problems - precise stimulus control and complex test logistics - are minimized in the Haploscope System, making it an ideal tool for research on binocular function. Moreover, incorporation of a system like the Haploscope into the standard ophthalmic examination would allow the clinician to include a comprehensive evaluation of binocular function as a standard aspect of the basic eye examination.

### 7.2.2 Simultaneous Objective and Subjective Measures of Binocular Function

The development of objective, on-line measures of eye position and state of accommodation and the availability of an instrument such as the Haploscope raises the possibility of combining objective and subjective measures of binocular function in a single instrument. If a measurement system were to be constructed which was capable of manipulating vergence angle, stimulus to accommodation and target configuration while at the same time objectively recording the relative positions of the subject's eyes and his accommodative response in at least one eye, it would be possible not only to carry out a comprehensive evaluation of the functional characteristics of that subject's binocular system but also to combine the objective and subjective data in an analysis designed to pinpoint a specific oculomotor dysfunction. An instrument with this capability would be expected to lead to significant improvement in the clinician's ability to predict the results of surgical and orthoptic treatment. Obviously, an instrument with this capability represents a considerable increase in sophistication over the current Baylor Mark III Haploscope. However, we do believe it will be possible to incorporate objective as well as subjective measurement capabilities into future versions of the Haploscope System.

### 7.3 The Haploscope and the Delivery of Eye Care

With the demand for health care services increasing at a high rate, and the cost of delivering those services increasing even more rapidly, there is a need to improve the efficiency of the delivery of all health care services. Good vision is fundamental to health, education

and economic productivity, and people are concerned about their eyes. Consequently, the need for improvements in the delivery of all eye care services is as great or greater than in any other aspect of health care delivery.

Significant increases in the efficiency of eye care delivery can be achieved in many areas, the most important of which, we believe, are in pre-examination visual testing and in the performance of the basic eye examination.

### 7.3.1 Pre-examination Screening

Traditionally, wall acuity charts or industrial type vision screeners have been used to identify those individuals in need of eye examinations. Such test procedures are poorly controlled (e.g. wall chart illumination levels), easily memorized, and often they yield a high percentage of false negatives.

Designed to minimize cost and complexity, a version of the Haploscope could be constructed which would serve as a binocular/monocular vision screening system. Such a system could test a number of subjects simultaneously, record all test data and compare results with norm group scores. The screening system would be applicable to the needs of school districts, HMO s, the Armed Forces and other groups concerned with the detection of ocular dysfunctions and anomalies. An expanded capability Haploscope System (short of the complete eye examination system described in the next section) could be used to obtain most of the eye data required in the yearly physical examination.

### 7.3.2 The Routine Eye Examination

Even more important is the considerable improvement in efficiency of the operation of the routine eye examination that could be achieved by:

1. the development of quantitative measures of visual anatomy and function which can be administered in the eye clinic by technicians in a standardized, automated manner; and
2. the reorganization of clinic personnel, equipment and facilities to make maximal use of all of the technological and manpower resources available.

Figure 32 shows how a coordinated eye care clinic based on these principles could work.

The new patient entering the clinic will provide biographical information for the computer data system to establish a patient file.

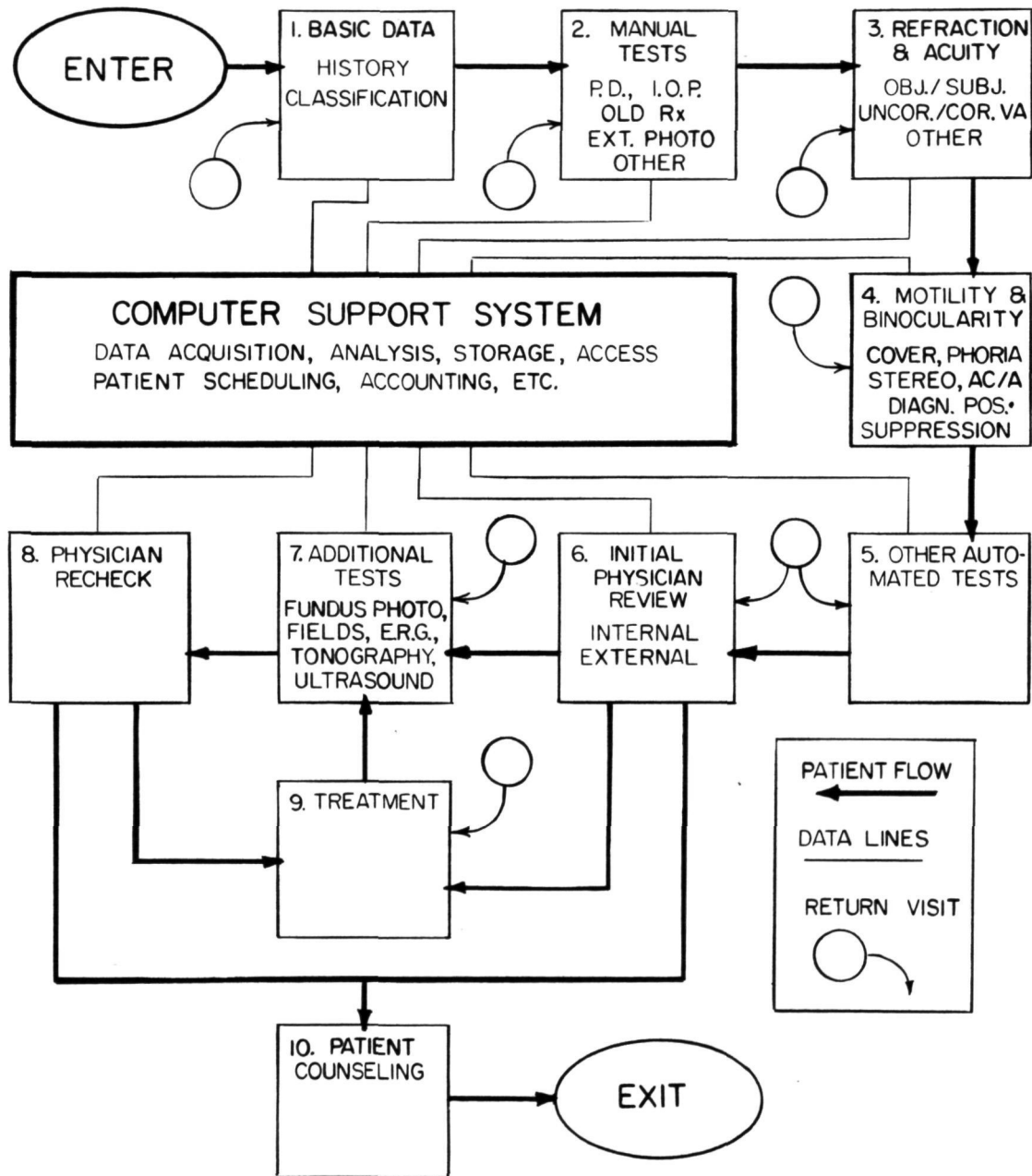


Figure 32. Block Diagram of the Coordinated Clinic Concept.

The patient then proceeds to a history-taking station where he answers questions asked by an interactive, branching history-taking program. Provisions are made for those patients who need questions in some non-visual form (e.g. auditory). A technician is responsible for instructing patients and aiding those who need help in the entry of their eye history data. A series of manual, individual tests (PD, old Rx, intra-ocular pressure, external photograph, etc.) are then carried out by a technician who enters the results into the clinic data system, by means of a CRT terminal, in a predetermined format. At the next test station, the patient receives a series of automated tests which measure his acuity and refractive status. If needed, an eyeglass prescription is generated and entered into the patient's record. After this test, the patient receives a series of automated eye motility/binocularity tests which determine the basic parameters of his oculomotor and oculosensory capabilities. Following these tests, the patient will be given other automated tests (to become available at a later date), or he will receive his initial review by the clinic eye specialist. At this point, all of the data relevant to the patient, including any available previous data, the nature of his present problem, and significant aspects of his history will be summarized and presented to the physician. The physician has the option of calling up raw data, previous test results, or any other information available from the computer data system. The physician then carries out the slit lamp examination, ophthalmoscopy and any other procedures he deems necessary. From this point the patient may exit from the clinic with the assurance of healthy eyes, he may receive a prescription for drugs or corrective lenses, or he may be reentered into the clinic system for additional diagnostic testing or retesting of previous data. Following any of these additional procedures, the patient again passes through the control and clinical judgment of the physician, and departs from the clinic as shown.

Such a reorganization of routine eye care delivery is possible and practical on the basis of resources currently available. The utilization of paramedical personnel for basic data collection frees the eye specialist to perform those tasks for which his skills and experience are absolutely necessary. The use of automated, quantitative measures of visual function, and the integration such data collection techniques into coordinated patient record keeping system can result in a considerable improvement of the quality of the care delivered. The significance of such an approach can be illustrated by the fact that a net overall increase in efficiency of as little as 10% could have the equivalent effect of training over 2200 new eye specialists.

In addition to its role in the space program, the Baylor Mark III Haploscope is, in fact, a limited capacity automated eye clinic, incorporating both quantitative measurement of visual function and optimization of available technological and manpower resources. The experimenters view the Haploscope System as the first step towards achieving the benefits of an automated eye care clinic.

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Appendix A

## Appendix A. The Film Target Photographic System

### 1.0 Requirements

The generation of the 16 mm film loops used as visual targets for the Baylor Mark III Haploscope requires the ability to produce a series of sharply focused, precisely centered, high resolution images of known size on each frame of the filmstrip. The photographic system constructed to generate these film loops consists of a 16 mm camera mounted on a carriage that moves up or down on a vertical column. In this way, the distance between the film plane of the camera and the artwork to be photographed is precisely varied, while the centering of the image in the film plane is preserved.

A drawing of the camera system constructed to produce these film loops is shown in Figure A1.

### 2.0 The System Components

#### 2.1 Camera

A Mitchell 16 mm movie camera was modified for convenient single frame operation. This camera is equipped with a Kodak 15 mm Ektar f/2.5 lens. An autofocus system was constructed to keep the artwork image sharply focused in the film plane regardless of the distance between the camera and the artwork platen. As shown in Figure A1, vertical movement of the camera carriage produces a movement of the autofocus chain. The chain rotates a cam mechanism which, in turn focuses the camera lens through a mechanical linkage. An electronic control unit operates the camera lights, times the film exposure, advances the film in either direction by single frames and keeps track of the frame number. Figure A2 is a photograph of the camera positioned to photograph the stereopsis target.

#### 2.2 Camera Stand

A Saltzberg single column animation stand was modified to accommodate the Mitchell 16 mm camera. A readout of the camera height above the table is provided through a mechanical counter driven by the autofocus chain as the camera is moved up and down. The animation stand table is equipped with a turntable centered on the camera axis so that the target artwork (e. g. Landolt C targets) can be photographed in different orientations. The vertical travel of the camera on the stand produces a reduction ratio range of approximately 12. Four 1000 Watt quartz-iodine lamps mounted approximately one

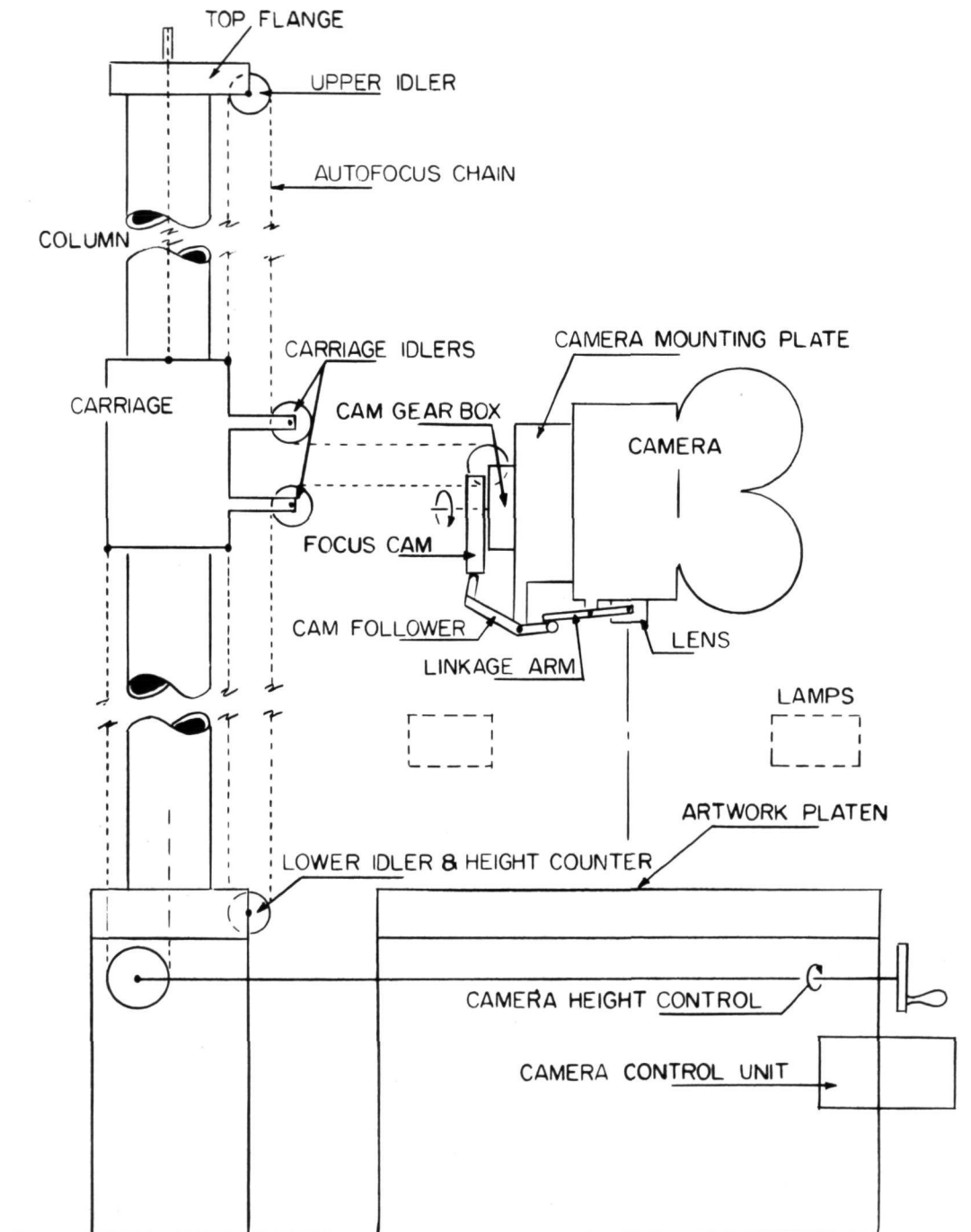


Figure A1. Diagram of the Film Target Photographic System.

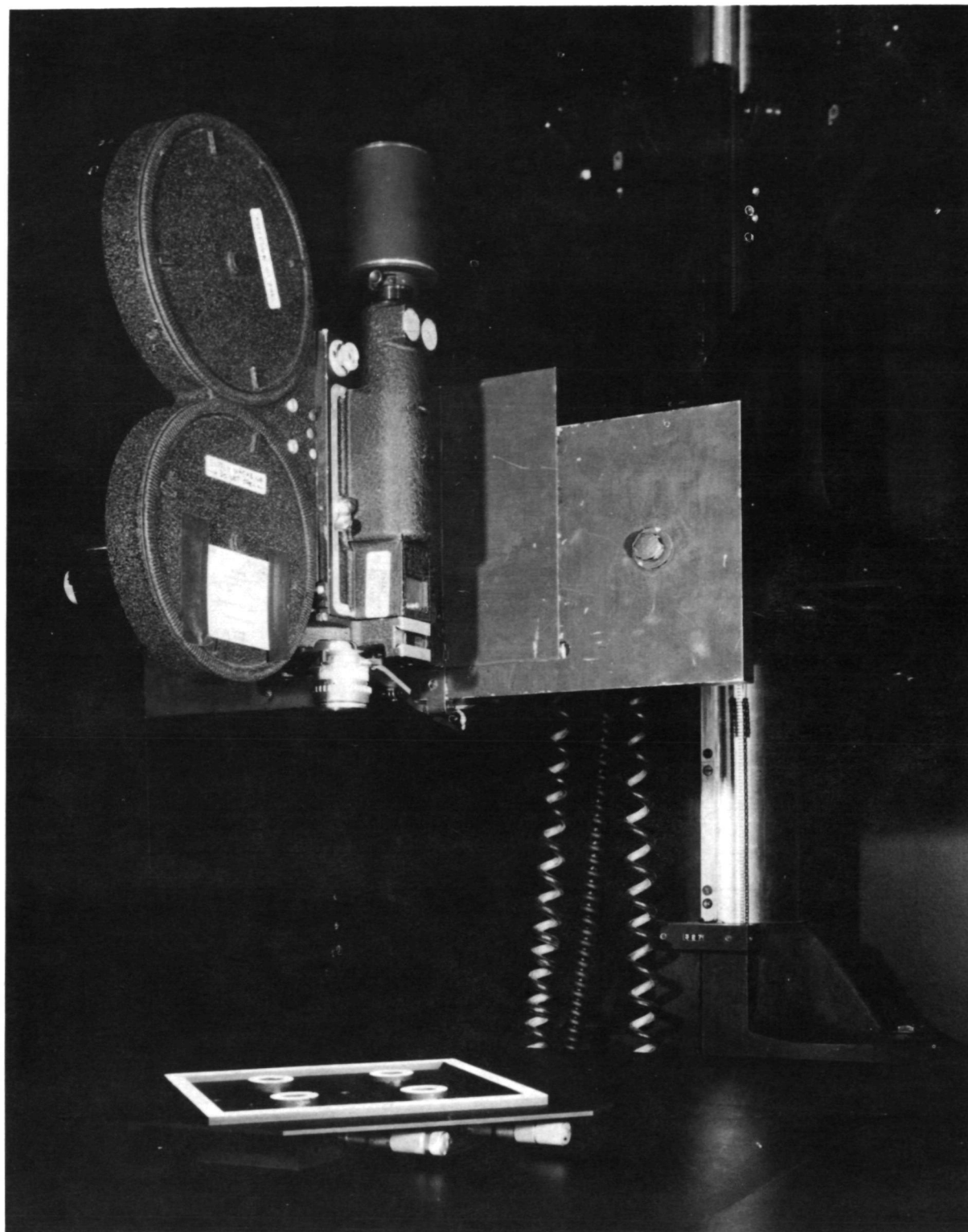


Figure A2. Photograph of the Film Target Photographic System Camera.

meter from the center of the artwork yield approximately 2500 foot-candles at the center of the artwork platen.

### 2.3 Film

Kodak Spectroscopic Film Type 649-GH is used for all Haploscope targetry. This film was selected because of its high resolution (2000 lines/mm), extremely fine granularity and high contrast characteristics. Moreover, the film is double perforated, with a 4 mil Estar base. The Estar base provides excellent dimensional stability while the double perforations aid accurate film registration in the Haploscope. Although the slow speed of the film (ASA = 0.04) requires relatively long exposures, the use of Kodak Spectroscopic film for the Haploscope imagery has proved highly satisfactory. The film is processed with Kodak HRP developer.

### 3.0 Artwork

The relationship between the image size on the film and the subtense of the target at the subject's eye is fixed by the Haploscope optics, so that approximately 2 mm (1.995 mm) on the film corresponds to  $1^\circ$  of visual angle at the eye. The relationship between the artwork size and the size of the image on the film is determined by the focal length of the camera lens and the distance to the artwork. Depending on the height of the camera above the artwork platen, the reduction ratios achieved with this system range from 1: 0.140 to 1: 0.011.

Accordingly, the one minute of arc gap of a 20/20 Landolt C viewed in the Haploscope corresponds to a film image size of  $1.995/60 = .033$  mm, and an artwork size ranging from  $.033/0.140 = .235$  mm to  $.033/.011 = 3.00$  mm. Similarly, a ten second disparity between two targets presented to the eyes in a test of stereopsis, corresponds to an artwork dimension ranging from  $1.995/(0.140 \cdot 360) = .039$  mm to  $1.995/(0.011 \cdot 360) = .503$  mm.

Although these size relationships created a few problems for the generation of most visual testing stimuli, the production of the stereopsis test film frames required the greatest precision in that the position of one part of the target relative to another (i.e. image disparity) needed to be accurately manipulated to less than 0.02 mm.

Figure A3 shows the artwork target constructed to produce these dimensional changes. The target consists of four circles or rings located inside a diamond shaped fusion frame. Slight alterations (disparities) in the position of any one ring in the film frame seen by one eye relative to the same ring seen in another film frame by the other eye are interpreted by the visual system as differences in depth. In the device shown, the four target rings are rollers moved by micrometer barrels by means of a rolamite mechanism which permits backlash free positioning of any one target ring relative to the remainder of the target. The precision of the visual system as a spatial disparity detector is illustrated by the fact that a threshold disparity at the eye of  $10''$  of arc corresponds to a film target disparity size of  $1.995/360 = .005$  millimeters or about 5 microns.

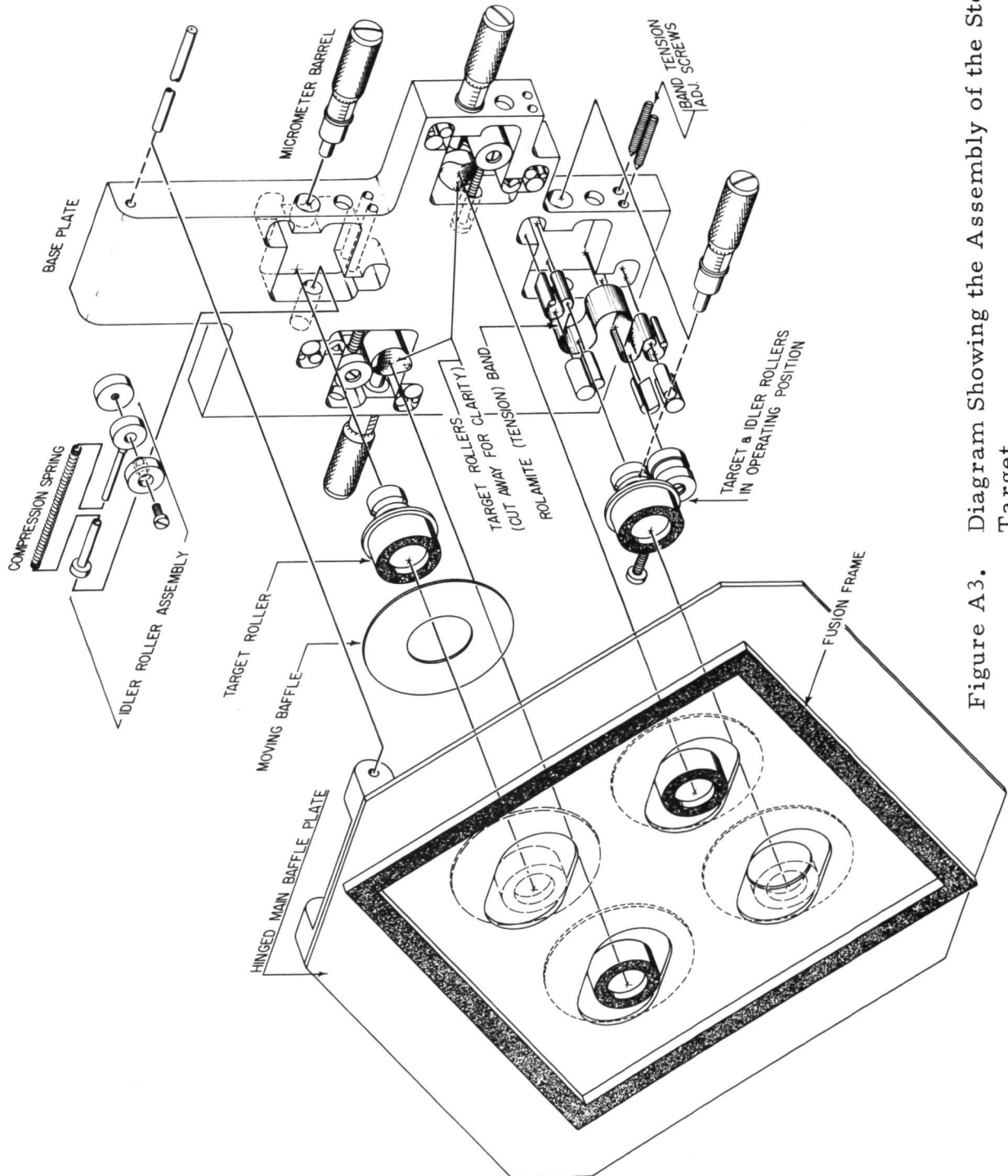


Figure A3. Diagram Showing the Assembly of the Stereopsis Target.

Appendix B

Assembly Diagrams of the Mechanical  
Parts of the Haploscope



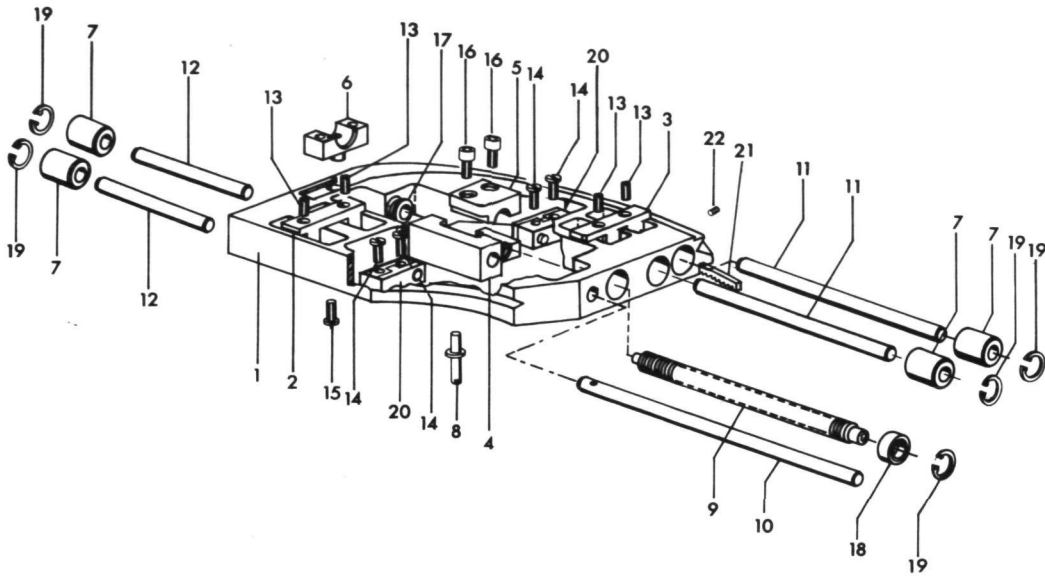


Figure B1. Exploded Parts Diagram of the Right Curved Track (Underside Shown on Top).

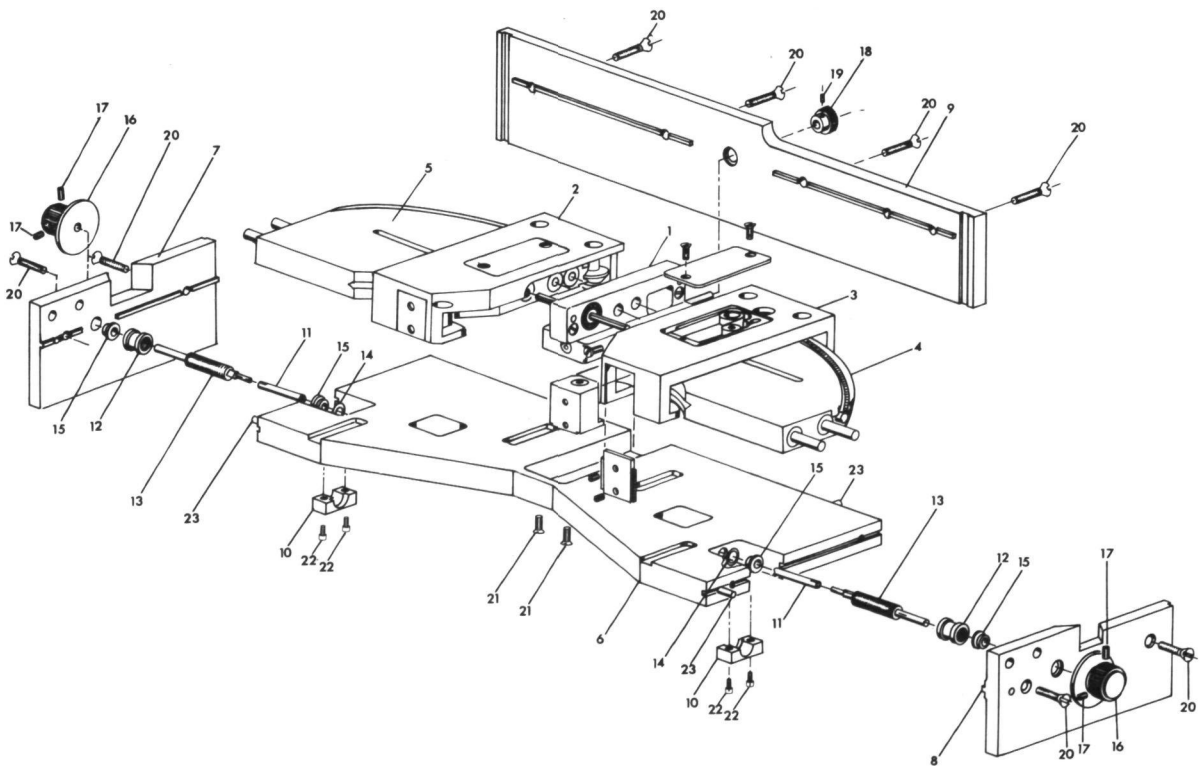


Figure B2. Exploded Parts Diagram of the Mechanical Base.

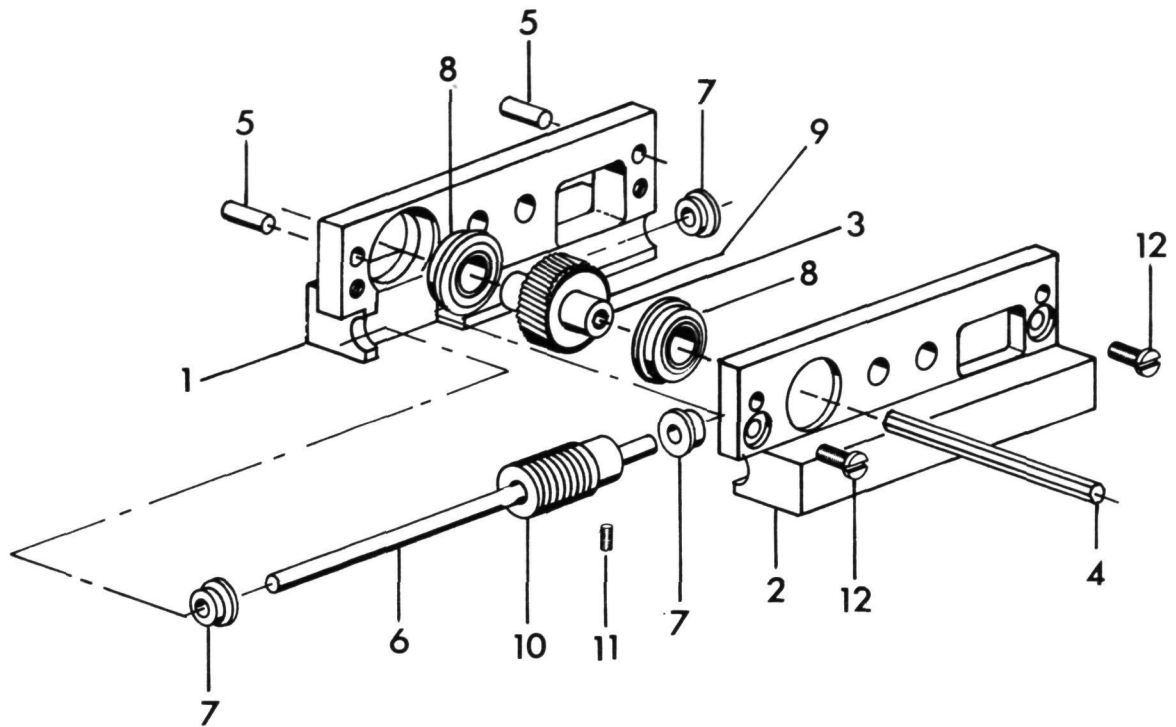


Figure B3. Exploded Parts Diagram of the Vergence Drive Worm and Gear Housing.

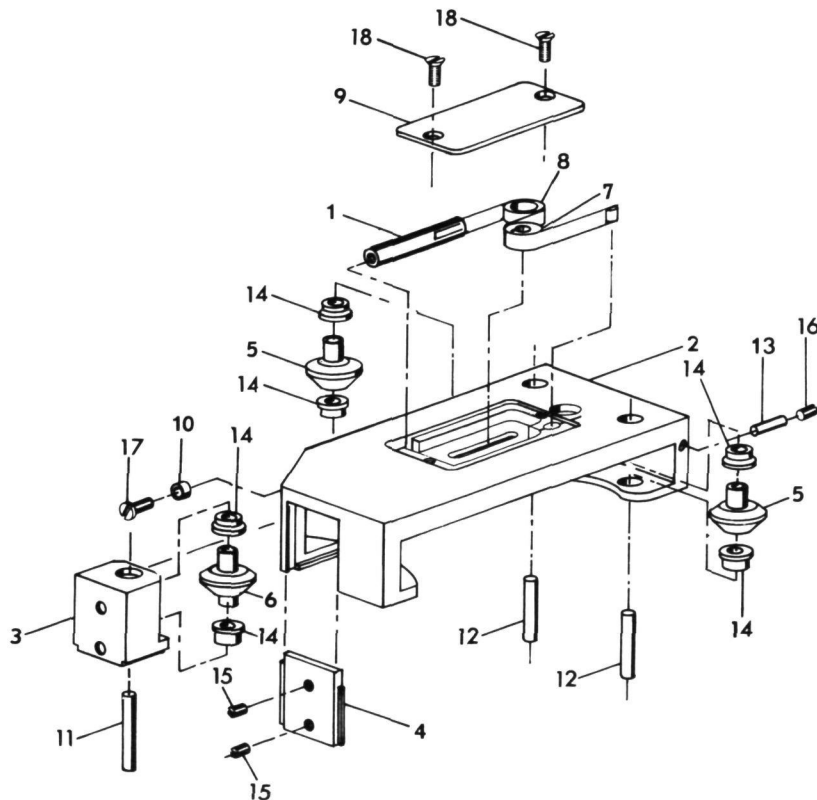


Figure B4. Exploded Parts Diagram of the Right Optical Assembly Platform.

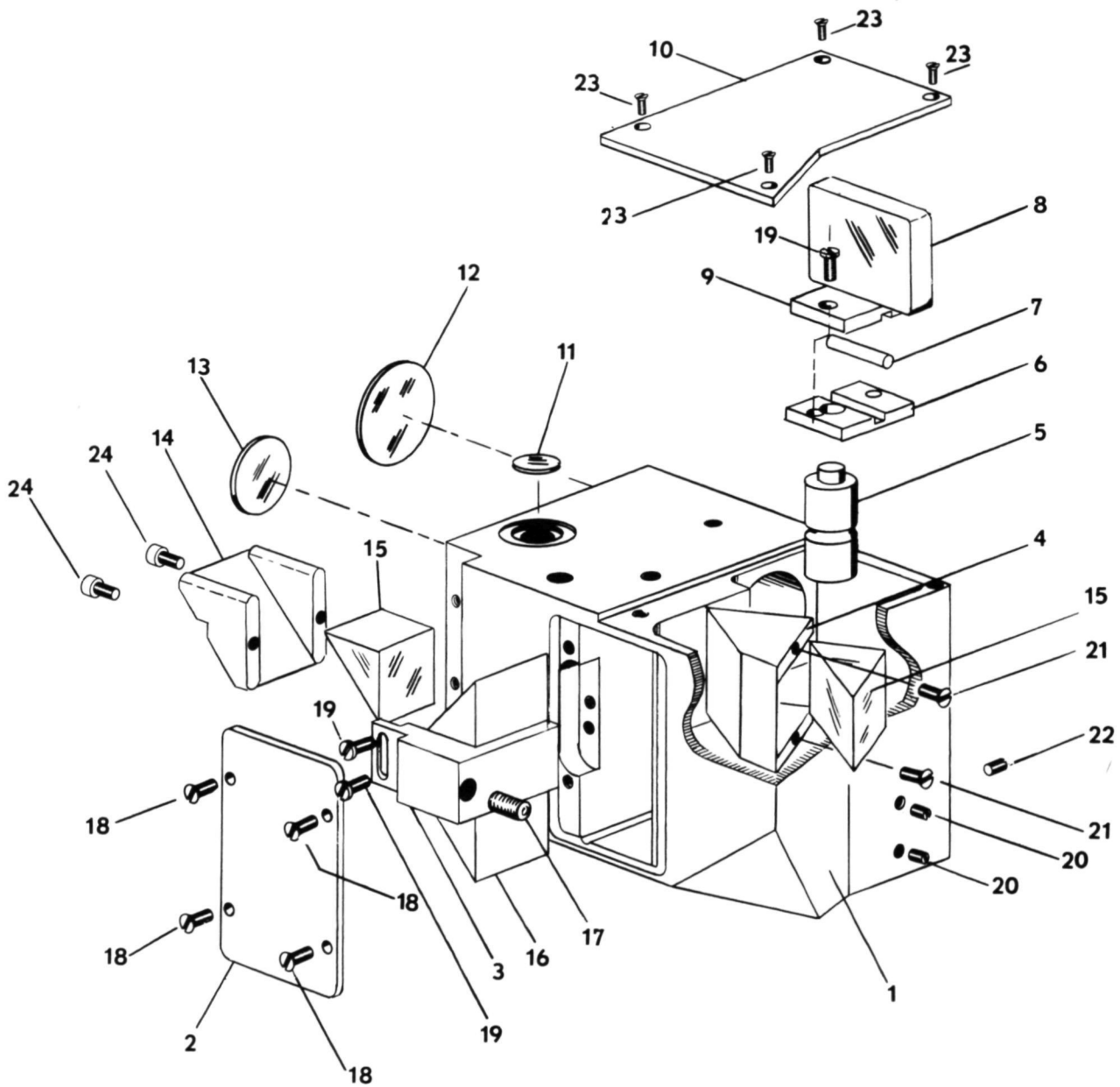


Figure B5. Exploded Parts Diagram of the Right Optical Assembly (Front Portion).

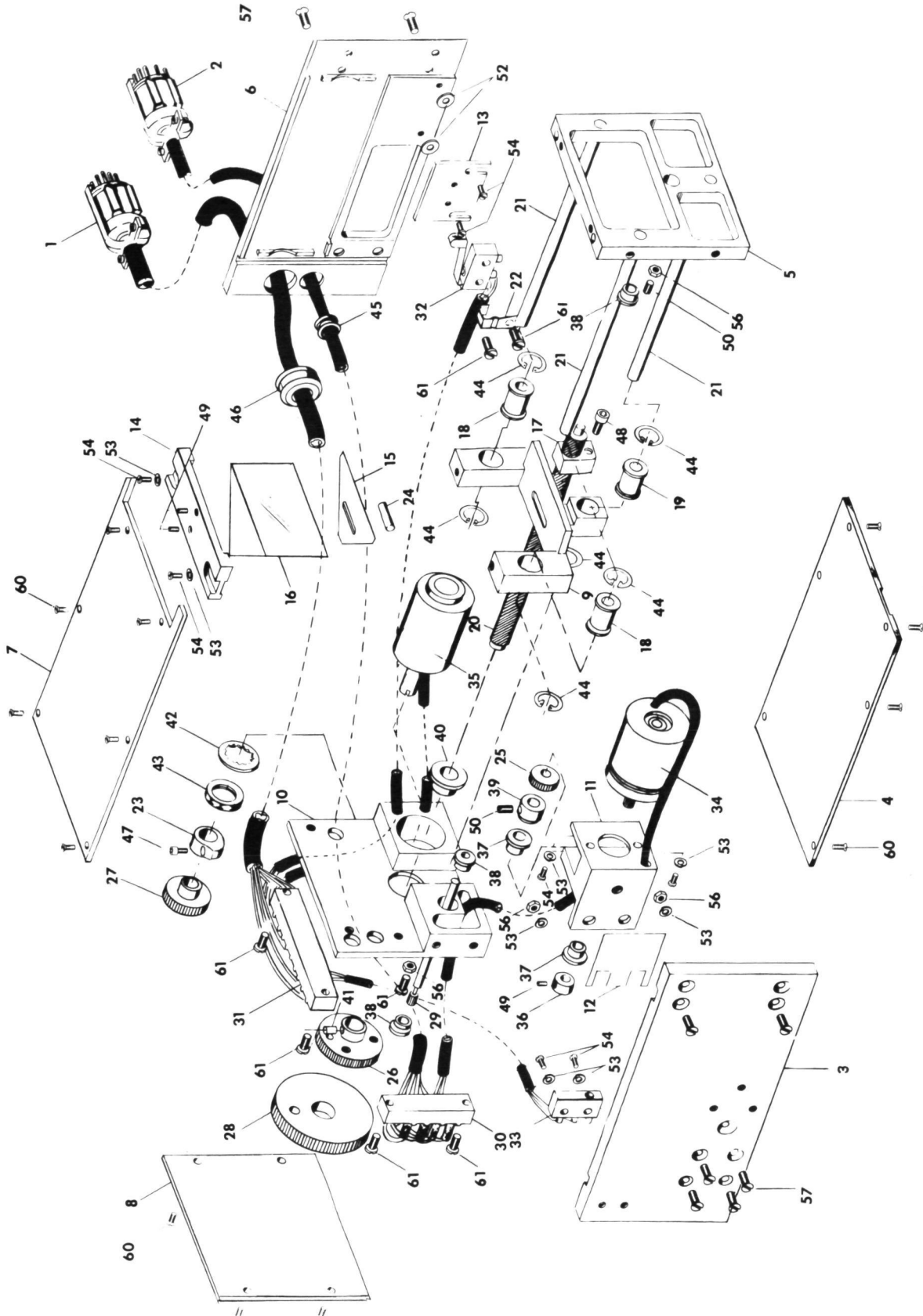


Figure B6. Exploded Parts Diagram of the Right Optical Assembly (Rear Portion).

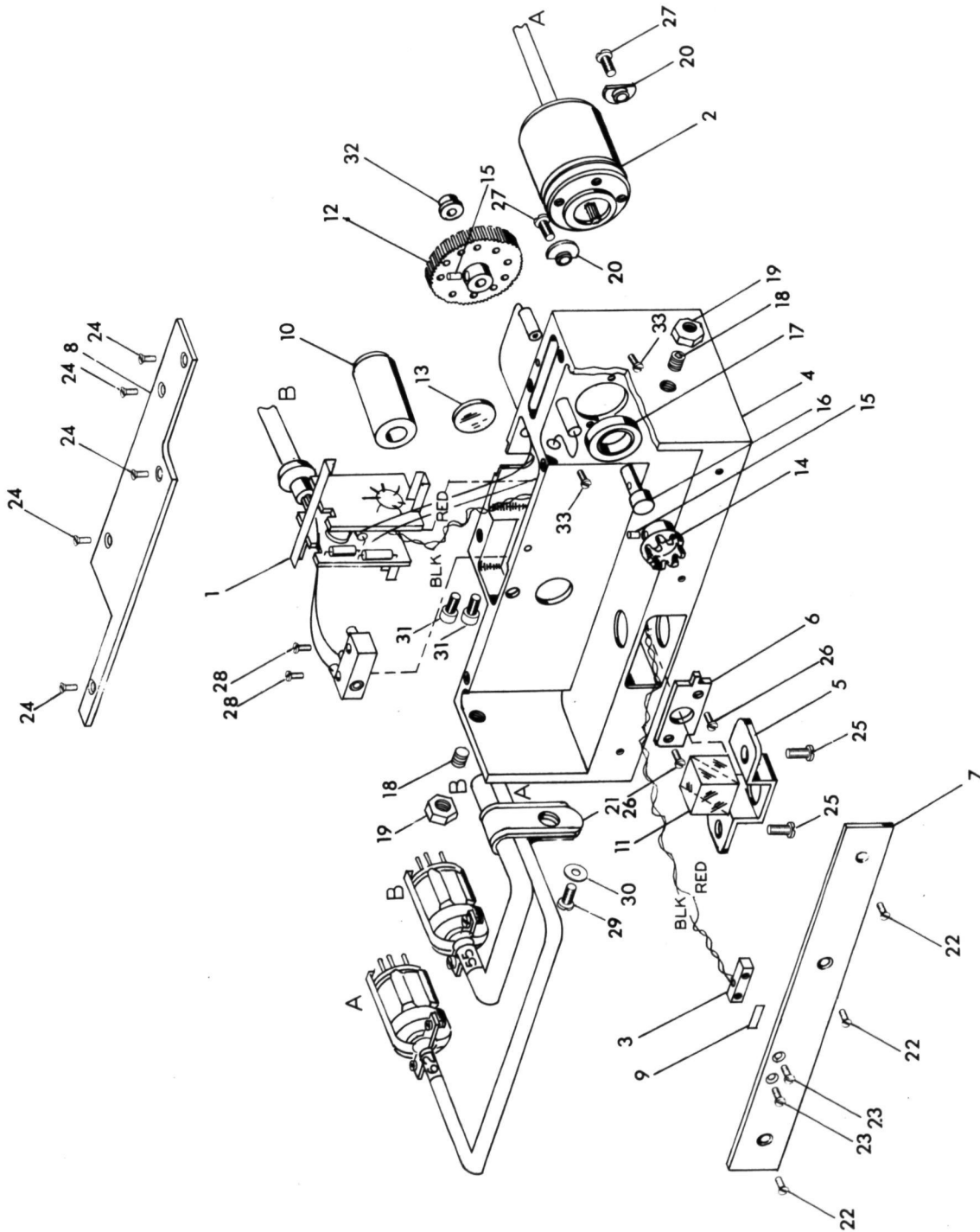


Figure B7. Exploded Parts Diagram of the Right Cassette Holder.

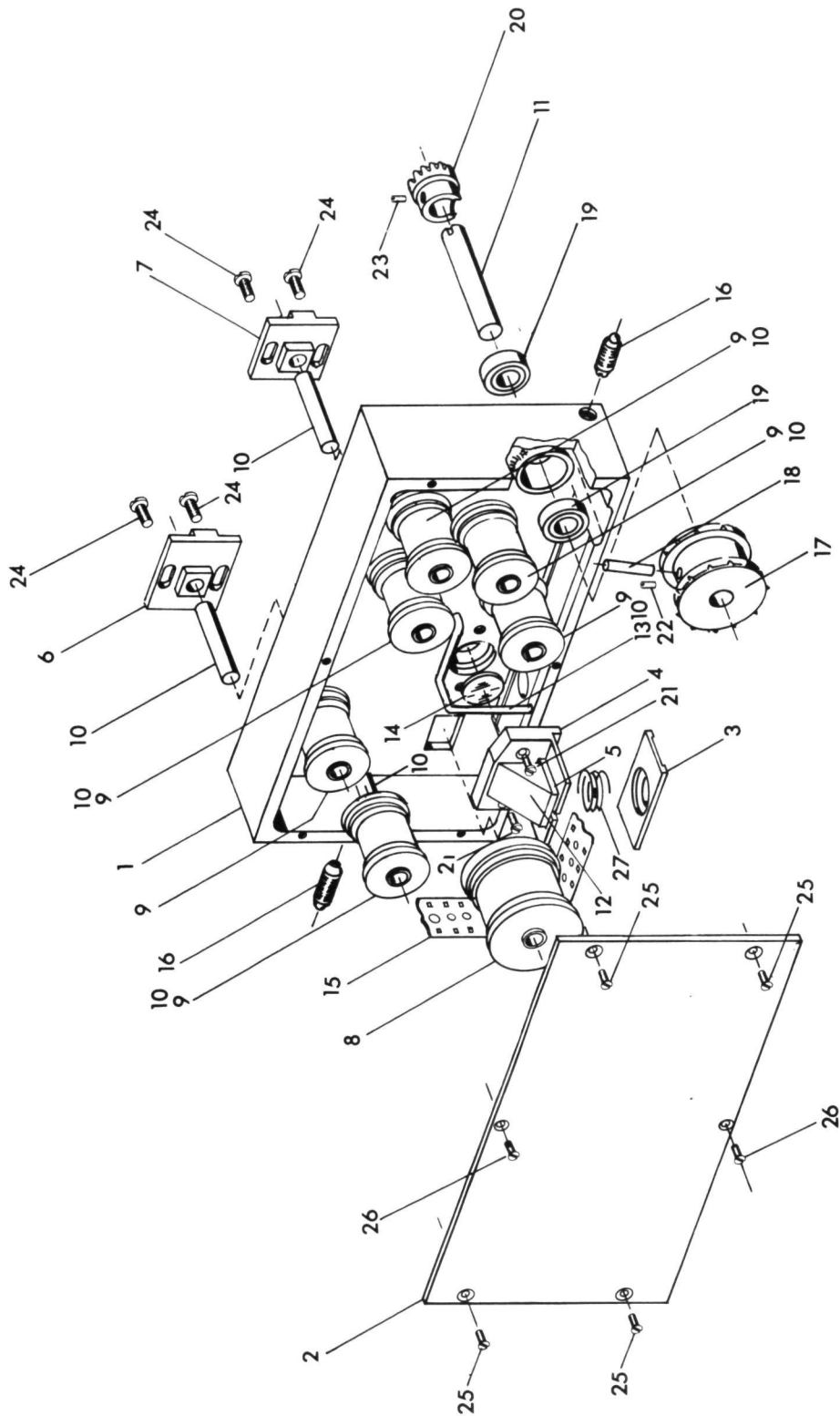


Figure B8. Exploded Parts Diagram of the Right Film Cassette.



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